Technical Overview

This technical section presents heat loss fundamentals along with basic problems and solutions. Data, charts and graphics are provided to aid in solving virtually any heating application using electric resistance type heaters.

Most materials, whether solid, liquid or gas may be readily heated with electric resistance heaters by conduction, convection or radiation. The following are three basic requirements, which when met, leave only the selection of type and number of electric heaters best suited for the application.

1. Final Temperature Desired —
Electric resistance heaters of the enclosed sheath type can be operated successfully over a wide range of temperatures from -300°F (cryogenic) to approximately 1500°F. For operating temperatures outside this range, contact the nearest Chromalox Application Engineering Sales office or factory.

2. Sheath Material Required —
Copper is commonly used as the sheath material for water applications, steel for oils, and Stainless Steel or INCOLOY® for corrosive solutions and high temperature air heating. This catalog gives considerable help in choosing the proper sheath material for many common materials. Additional help is available from the nearest Chromalox Application Engineering Sales office or factory.

3. Watt Density Permitted —
Watt density is the heat energy emanating from each square inch of heated surface of a heater or element. Some materials such as water, vegetable oils and salt baths can withstand a high watt density, while others such as petroleum oils or sugar syrups must use lower watt densities. These liquids do not readily absorb or conduct the heat being generated. If the watt density is too high, carbonization or overheating may damage the heating equipment or material being heated. Recommended maximum ratings for various materials and temperature conditions are included in this section. All heaters in this catalog have the watt density specified for standard heater ratings.

After resolving the above requirements, choose the type of heater best suited to the application. For example, a tank of water may be heated by direct immersion heaters, by clamp-on strip, ring or tubular heaters or a side-arm circulation heater. The choice will depend on the process, considerations, available space both inside and outside, economy, maintenance, etc.

General Guidelines for Heater Type, Selection & Application

Heated Media

LIQUIDS
For highest efficiency and fastest response, use direct immersion
- Flange heaters
- Screw plug heaters
- Over-the-side heaters
- Circulation heaters—side-arm, in-line or booster applications

SOLIDS
For dies, molds, platens, soft metals, use
- Clamp-on types—strips or tubular elements
- Cartridge heaters
- Cast-in heaters
- Radiant heaters
- Melting pots

LIQUIDS
When conditions do not permit direct immersion heaters, use
- Clamp-on types—strips, tubular, cast-in, heating cable
- Radiant heaters
- Heat transfer systems
- Electric hot water or steam boilers

GASES
For gases in ducts, ovens or pipelines use
- Strip or Finstrip® elements
- Tubular or Fintube® elements
- Duct heaters
- Circulation heaters
- Flange or screw plug heaters in pipeline systems

Application Design Criteria

Provide enough kW and
- Closely match connected load to application requirements for best product and process control
- Avoid installing excess capacity over the base load and required safety factor

Design for long life by
- Keeping sheath temperatures well below maximum recommendations
- Using lowest line voltage practical where choices are available

Ensure safe operating conditions by providing
- Heater equipment with suitable operating control and overheat protection devices
- Process being heated with .suitable controls
- Electrical wiring in accordance with all national and local codes
- Protection for personnel by using insulation, guards, grilles and warning labels

Protect equipment from
- Physical damage
- Terminal contamination
- Corrosion
- Excessive wiring and terminal temperatures

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Note — The facts and recommendations made in this publication are based on data assembled from various sources, our own research and the research of others. Although every attempt has been made to ensure accuracy, neither Chromalox nor the contributors to this publication assume responsibility for any inaccuracies or omissions in the data presented.

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Technical Information

Heat Transfer Fundamentals & Thermodynamic Properties

Heat Transfer Fundamentals

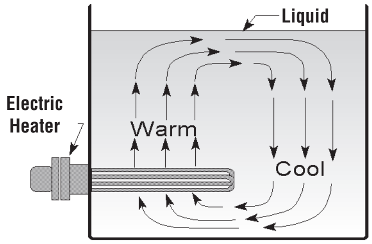
The principles of heat transfer are well understood and are briefly described below. Heat energy is transferred by three basic modes. All heating applications involve each mode to a greater or lesser degree.

- Conduction
- Convection
- Radiation

Conduction is the transfer of heat energy through a solid material. Metals such as copper and aluminum are good conductors of heat energy. Glass, ceramics and plastics are relatively poor conductors of heat energy and are frequently used as thermal insulators. All gases are poor conductors of heat energy. A combination of expanded glass or ceramic fiber filled with air is excellent thermal insulation. Typical conduction heating applications include platen heating (cartridge heaters), tank heating (strip and ring heaters), pipe tracing and other applications where the heater is in direct contact with the material being heated.

Convection is the transfer of heat energy by circulation and diffusion of the heated media. It is the most common method of heating fluids or gases and also the most frequent application of electric tubular elements and assemblies. Fluid or gas in direct contact with a heat source is heated by conduction causing it to expand. The expanded material is less dense or lighter than its surroundings and tends to rise. As it rises, gravity replaces it with colder, denser material which is then heated, repeating the cycle. This circulation pattern distributes the heat energy throughout the media. Forced convection uses the same principle except that pumps or fans move the liquid or gas instead of gravity.

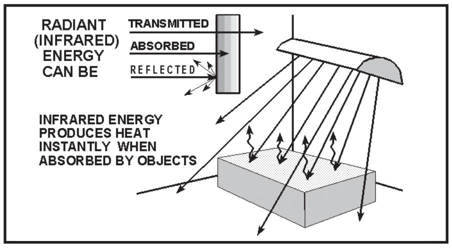
Convection in a Liquid



Typical convection heating applications include water and oil immersion heating, air heating, gas heating and comfort air heating.

Radiation is the transfer of heat energy by electromagnetic (infrared) waves and is very different from conduction and convection. Conduction and convection take place when the material being heated is in direct contact with the heat source. In infrared heating, there is no direct contact with the heat source. Infrared energy travels in straight lines through space or vacuum (similar to light) and does not produce heat energy until absorbed. The converted heat energy is then transferred in the material by conduction or convection.

Radiant Energy (Infrared) Heating



All objects above "absolute zero" temperature radiate infrared energy with warmer objects radiating more energy than cooler objects. Infrared energy radiating from a hot object (heating element) strikes the surface of a cooler object (work piece), is absorbed and converted to heat energy. Paint drying by radiant heaters is a typical application of infrared heating. The most important principle in infrared heating is that infrared energy radiates from the source in straight lines and **does not become heat energy until absorbed by the work product.**

Thermodynamic Properties

All materials have basic physical constants and thermodynamic properties. These constants are used in the evaluation of the materials and in heat energy calculations. The constants and properties most often used are:

- Specific Heat (C_p)
- Heat of Fusion (H_{fus})
- Heat of Vaporization (H_{vap})
- Thermal Conductivity (k)
- Thermal Resistivity (R)

Specific Heat (Quantity of Heat Energy) — All materials contain or absorb heat energy in differing amounts. The quantity of heat energy or thermal capacity of a particular material is called its **specific heat**.

The specific heat of a substance is defined as the amount of heat energy required to raise one pound of the material by one degree Fahrenheit. Specific heat factors are usually defined as British thermal units per pound per degree Fahrenheit **(Btu/lb/°F)**. The specific heat of most materials is constant at only one temperature and usually varies to some degree with temperature. Water has a specific heat of 1.0 and absorbs large quantities of heat energy. Air, with a specific heat of 0.24, absorbs considerably less heat energy per pound.

Heat of Fusion or Vaporization — Many materials can change from a solid to a liquid to a gas. For the change of state to occur, heat energy must be added or released. Water is a prime example in that it changes from a solid (ice) to a liquid (water) to a gas (steam or vapor). If the change is from a solid to a liquid to a gas, heat energy is added. If the change is from a gas to a liquid to a solid, heat energy is released. These energy requirements are called the **heat of fusion** and the **heat of vaporization**. They are expressed as Btu per pound **(Btu/lb)**.

- **Heat of Fusion** is the amount of energy required to transform a material from a solid to a liquid (or the reverse) at the same temperature. Water has a heat of fusion of 143 Btu/lb.
- **Heat of Vaporization** is the amount of energy required to transform a material from a liquid to a gas (or the reverse) at the same temperature. Water has a high heat of vaporization, 965 Btu/lb. Water can transfer large amounts of heat energy in the form of condensing steam.

Thermal Conductivity is the ability of a material to transmit heat energy by conduction. Thermal conductivity is identified as *"k"* and is usually expressed in British thermal units per linear inch (or foot) per hour per square foot of area per degree Fahrenheit. **(Btu/in/hr/ft^2/°F) or (Btu/ft/hr/ft^2/°F)**. *"k"* factors are used extensively in comfort heating applications to rate the effectiveness of building construction and other materials as thermal insulation. *"k"* factors are also used in the calculation of heat losses through pipe and tank insulation.

Thermal Resistivity or "R" is the inverse of thermal conductivity. Insulating materials are rated by "R" factors. The higher the "R" factor, the more effective the insulation.

Technical Information

Determining Heat Energy Requirements

General Applications

The objective of any heating application is to raise or maintain the temperature of a solid, liquid or gas to or at a level suitable for a particular process or application. Most heating applications can be divided into two basic situations; applications which require the maintenance of a constant temperature and applications or processes which require work product to be heated to various temperatures. The principles and calculation procedures are similar for either situation.

Constant Temperature Applications

Most constant temperature applications are special cases where the temperature of a solid, liquid or gas is maintained at a constant value regardless of ambient temperature. Design factors and calculations are based on steady state conditions at a fixed difference in temperature. Heat loss and energy requirements are estimated using "worst case" conditions. For this reason, determining heat energy requirements for a constant temperature application is relatively simple. Comfort heating (constant air temperature) and freeze protection for piping are typical examples of constant temperature applications. The equations and procedures for calculating heat requirements for several applications are discussed later in this section.

Variable Temperature Applications

Variable temperature (process) applications usually involve a start-up sequence and have numerous operating variables. The total heat energy requirements for process applications are determined as the sum of these calculated variables. As a result, the heat energy calculations are usually more complex than for constant temperature applications. The variables are:

Total Heat Energy Absorbed — The sum of all the heat energy absorbed during start-up or operation including the work product, the latent heat of fusion (or vaporization), make up materials, containers and equipment.

Total Heat Energy Lost — The sum of the heat energy lost by conduction, convection, radiation, ventilation and evaporation during start-up or operation.

Design Safety Factor — A factor to compensate for unknowns in the process or application.

Process Applications

The selection and sizing of the installed equipment in a process application is based on the **larger of two calculated heat energy requirements**. In most process applications, the start-up and operating parameters represent two distinctly different conditions in the same process. The heat energy required for start-up is usually considerably different than the energy required for operating conditions. In order to accurately assess the heat requirements for an application, each condition must be evaluated. The comparative values are defined as follows:

- **Calculated heat energy required for process start-up over a specific time period.**
- **Calculated heat energy required to maintain process temperatures and operating conditions over a specific cycle time.**

Determining Heat Energy Absorbed

The first step in determining total heat energy requirements is to determine the heat energy absorbed. If a change of state occurs as a direct or indirect part of the process, the heat energy required for the change of state must be included in the calculations. This rule applies whether the change occurs during start-up or later when the material is at operating temperature. Factors to be considered in the heat absorption calculations are shown below:

Start-Up Requirements (Initial Heat-Up)

- Heat absorbed during start-up by:
  - Work product and materials
  - Equipment (tanks, racks, etc.)
- Latent heat absorption at or during start-up:
  - Heat of fusion
  - Heat of vaporization
- Time factor

Operating Requirements (Process)

- Heat absorbed during operation by:
  - Work product in process
  - Equipment loading (belts, racks, etc.)
  - Make up materials
- Latent heat absorption during operation:
  - Heat of fusion
  - Heat of vaporization
- Time (or cycle) factor, if applicable

Determining Heat Energy Lost

Objects or materials at temperatures above the surrounding ambient lose heat energy by conduction, convection and radiation. Liquid surfaces exposed to the atmosphere lose heat energy through evaporation. The calculation of total heat energy requirements must take these losses into consideration and provide sufficient energy to offset them. Heat losses are estimated for both start-up and operating conditions and are added into the appropriate calculation.

Heat Losses at Start-Up — Initially, heat losses at start-up are zero since the materials and equipment are all at ambient temperature. Heat losses increase to a maximum at operating temperature. Consequently, start-up heat losses are usually based on an average of the loss at start-up and the loss at operating temperature.

Heat Losses at Operating Temperature — Heat losses are at a maximum at operating temperature. Heat losses at operating temperature are taken at full value and added to the total energy requirements.

Estimating Heat Loss Factors

The heat losses just discussed can be estimated by using factors from the charts and graphs provided in this section. Total losses include radiation, convection and conduction from various surfaces and are expressed in watts per hour per unit of surface area per degree of temperature **(W/hr/ft²/°F)**.

Note — Since the values in the charts are already expressed in watts per hour, they are not influenced by the time factor *"t"* in the heat energy equations.

Design Safety Factors

In many heating applications, the actual operating conditions, heat losses and other factors affecting the process can only be estimated. A safety factor is recommended in most calculations to compensate for unknowns such as ventilation air, thermal insulation, make up materials and voltage fluctuations. As an example, a voltage fluctuation (or drop) of 5% creates a 10% change in the wattage output of a heater.

Safety factors vary from 10 to 25% depending on the level of confidence of the designer in the estimate of the unknowns. The safety factor is applied to the sum of the calculated values for heat energy absorbed and heat energy lost.

Technical Information

Determining Heat Energy Requirements

Total Heat Energy Requirements

The total heat energy (Q_T) required for a particular application is the sum of a number of variables. The basic total energy equation is:

$$Q_T = Q_M + Q_L + \text{Safety Factor}$$

Where:
Q_T = The total energy required in kilowatts
Q_M = The total energy in kilowatts absorbed by the work product including latent heat, make up materials, containers and equipment
Q_L = The total energy in kilowatts lost from the surfaces by conduction, convection, radiation, ventilation and evaporation
Safety Factor = 10% to 25%

While Q_T is traditionally expressed in Btu's (British Thermal Units), it is more convenient to use watts or kilowatts when applying electric heaters. Equipment selection can then be based directly on rated heater output. Equations and examples in this section are converted to watts.

Basic Heat Energy Equations

The following equations outline the calculations necessary to determine the variables in the above total energy equation. Equations 1 and 2 are used to determine the heat energy absorbed by the work product and the equipment. The specific heat and the latent heat of various materials are listed in this section in tables of properties of non-metallic solids, metals, liquids, air and gases. Equations 3 and 4 are used to determine heat energy losses. Heat energy losses from surfaces can be estimated using values from the curves in charts G-114S, G-125S, G-126S or G-128S. Conduction losses are calculated using the thermal conductivity or *"k"* factor listed in the tables for properties of materials.

Equation 1 — Heat Energy Required to Raise the Temperature of the Materials (No Change of State). The heat energy absorbed is determined from the weight of the materials, the specific heat and the change in temperature. Some materials, such as lead, have different specific heats in the different states. When a change of state occurs, two calculations are required for these materials, one for the solid material and one for the liquid after the solid has melted.

$$Q_A = \frac{\text{Lbs} \times C_p \times \Delta T}{3412 \text{ Btu/kW}}$$

Where:
Q_A = kWh required to raise the temperature
Lbs = Weight of the material in pounds
C_p = Specific heat of the material (Btu/lb/°F)
ΔT = Change in temperature in °F
$[T_{2\,(\text{Final})} - T_{1\,(\text{Start})}]$

Equation 2 — Heat Energy Required to Change the State of the Materials. The heat energy absorbed is determined from the weight of the materials and the latent heat of fusion or vaporization.

$$Q_F \text{ or } Q_V = \frac{\text{Lbs} \times H_{fus} \text{ or } H_{vap}}{3412 \text{ Btu/kW}}$$

Where:
Q_F = kWh required to change the material from a solid to a liquid
Q_V = kWh required to change the material from a liquid to a vapor or gas
Lbs = Weight of the material in pounds
Q_{fus} = Heat of fusion (Btu/lb/°F)
Q_{vap} = Heat of vaporization (Btu/lb/°F)

Equation 3 — Heat Energy Lost from Surfaces. The heat energy lost from surfaces by radiation, convection and evaporation is determined from the surface area and the loss rate in watts per square foot per hour.

$$Q_{LS} = \frac{A \times L_S}{1000 \text{ W/kW}}$$

Where:
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
A = Area of the surfaces in square feet
L_S = Loss rate in watts per square foot at final temperature (W/ft^2/hr from charts)[1]

Equation 4 — Heat Energy Lost by Conduction through Materials or Insulation. The heat energy lost by conduction is determined by the surface area, the thermal conductivity of the material, the thickness and the temperature difference across the material.

$$Q_{LC} = \frac{A \times k \times \Delta T}{d \times 3412 \text{ Btu/kW}}$$

Where:
Q_{LC} = kWh lost by conduction
A = Area of the surfaces in square feet
k = Thermal conductivity of the material in Btu/inch/square foot/hour (Btu/in/ft^2/hr)
ΔT = Temperature difference in °F across the material $[T_2 - T_1]$
d = Thickness of the material in inches

Summarizing Energy Requirements

Equations 5a and 5b are used to summarize the results of all the other equations described on this page. These two equations determine the total energy requirements for the two process conditions, start-up and operating.

Equation 5a — Heat Energy Required for Start-Up.

$$Q_T = \left(\frac{Q_A + Q_F\,[\text{or } Q_V]}{t} + \frac{Q_{LS} + Q_{LC}}{2}\right)(1 + \text{SF})$$

Where:
Q_T = The total energy required in kilowatts
Q_A = kWh required to raise the temperature
Q_F = kWh required to change the material from a solid to a liquid
Q_V = kWh required to change the material from a liquid to a vapor or gas
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
Q_{LC} = kWh lost by conduction
SF = Safety Factor (as a percentage)
t = Start-up time in hours[2]

Equation 5b — Heat Energy Required to Maintain Operation or Process[3].

$$Q_T = (Q_A + Q_F\,[\text{or } Q_V] + Q_{LS} + Q_{LC})(1 + \text{SF})$$

Where:
Q_T = The total energy required in kilowatts
Q_A = kWh required to raise the temperature of added material
Q_F = kWh required to change added material from a solid to a liquid
Q_V = kWh required to change added material from a liquid to a vapor or gas
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
Q_{LC} = kWh lost by conduction
SF = Safety Factor (as a percentage)

Equipment Sizing & Selection

The size and rating of the installed heating equipment is based on the larger of calculated results of Equation 5a or 5b.

Notes —

1. **Loss Factors** from charts in this section include losses from radiation, convection and evaporation unless otherwise indicated.
2. **Time (*t*)** is factored into the start-up equation since the start up of a process may vary from a period of minutes or hours to days.
3. **Operating Requirements** are normally based on a standard time period of one hour ($t = 1$). If cycle times and heat energy requirements do not coincide with hourly intervals, they should be recalculated to a hourly time base.

Technical Information

Determining Heat Energy Requirements - Heating Liquids

Typical Steps in Determining Total Energy Requirements

Most heating problems involve three basic steps:

1. **Determine** required kW capacity for bringing application up to operating temperature in the desired time.
2. **Calculate** the kW capacity required to maintain the operating temperature.
3. **Select** the number and type of heaters required to supply the kW required.

Note — Some applications, such as instantaneous heating of gas or air in ducts, comfort heating and pipe tracing only require calculation of the operating kW and selection of heaters.

Design Considerations

In order to calculate the initial and operating kW capacity requirements, the following factors should be considered:

- Specified heat-up time
- Start-up and operating temperatures
- Thermal properties of material(s) being heated
- Weight of material(s) being heated
- Weight of container and equipment being heated
- Weight of make up material (requirements per hour)
- Heat carried away by products being processed or equipment passing through heated area
- Heat absorbed due to a change of state
- Thermal properties and thickness of insulation
- Heat losses from the surface of material and/or container to the surrounding environment.

Liquid Heating Example

One of the most common electric heating applications is the direct immersion heating of liquids. The following example illustrates the steps in determining total energy requirements of a typical direct immersion application.

Application — A final rinse tank requires water at 180°F. The tank is 2 feet wide by 4 feet long by 2 feet high and is uninsulated with an open top. The tank is made of 3/8” steel and contains 100 gallons of water at 70°F at start up. Make up water with a temperature of 60°F is fed into the tank at the rate of 40 gallons per hour during the process. There is an exhaust hood over the tank and the relative humidity in the area is high. Work product is 300 lbs. of steel per hour.

Example — Heat the water to 180°F in 3 hours and heat 40 gallons per hour of make up water from 60°F to 180°F thereafter.

Specific heat of steel = 0.12 Btu/lb/°F
Specific heat of water = 1.00 Btu/lb/°F
Weight of steel = 490 lb/ft^3
Weight of water = 8.345 lb/gal

To Find Initial (Start-Up) Heating Capacity —

$$Q_S = \left(\frac{Q_A + Q_C}{t} + \frac{Q_{LS}}{2}\right)(1 + SF)$$

Where:
Q_S = The total energy required in kilowatts
Q_A = kWh required to raise the temperature of the water
Q_C = kWh required to raise the temperature of the steel tank
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
SF = Safety Factor
t = Start-up time in hours (3)

kW to Heat Water —

$$\frac{100 \text{ gal} \times 8.345 \text{ lb/gal} \times 1.0 \text{ Btu/lb } (180 - 70°\text{F})}{3412 \text{ Btu/kW}}$$

Q_A = 26.9 kW

kW to Heat Steel Tank —

Lbs of steel = Area x thickness x 490 lbs/ft^3

$$32 \text{ ft}^2 \times \frac{0.375 \text{ in.}}{12} \times 490 \text{ lb/ft}^3 = 490 \text{ lbs}$$

$$\frac{490 \text{ lbs} \times 0.12 \text{ Btu/lb } (180 - 70°\text{F})}{3412 \text{ Btu/kW}}$$

Q_C = 1.89 kW

Heat Losses from Surfaces —

$Q_{LS} = L_{SW} + L_{SC}$

Where:
Q_{LS} = kWh lost from all surfaces
L_{SW} = Losses from the surface of the water
L_{SC} = Losses from the surfaces of the tank

L_{SW} = Surface losses from water (Graph G114S, Curve 2 fps @ 60% rh)

$$\frac{8 \text{ ft}^2 \times 550 \text{ W/ft}^2}{1000 \text{ W/kW}} = 4.4\text{kW}$$

L_{SC} = Surface losses from uninsulated tank walls (Graph G125S)

$$\frac{32 \text{ ft}^2 \times 0.6 \text{ W/ft}^2 \times (180 - 70°\text{F})}{1000 \text{ W/kW}} = 2.11 \text{ kW}$$

Heat Required for Start-Up —

$$\left(\frac{26.9 \text{ kW} + 1.89 \text{ kW}}{3 \text{ hrs}} + \frac{4.4 \text{ kW} + 2.11 \text{ kW}}{2}\right) \times 1.2$$

Q_S = 15.42 kW

To Find Heat Required for Operating —

$Q_O = (Q_{WO} + Q_{LS} + Q_{WS})(1 + SF)$

Where:
Q_{WO} = kW to heat additional water

$$\frac{40 \text{ gal} \times 8.345 \text{ lb/gal} \times 1.0 \text{ Btu/lb } (180 - 60°\text{F})}{3412 \text{ Btu/kW}}$$

Q_{WO} = 11.7 kW

Q_{WS} = kW to heat steel 300 Lbs. x 0.12 x (180 - 60°F)/3412 = 1.27 kW

Heat Required for Operating —

Q_O = (11.7 kW + 1.27 kW + 4.4 kW + 2.11 kW) 1.2

Q_O = 23.38 kW

Installed Capacity — Since the heat required for operating (21.85 kW) is greater than the heat required for start up (15.42 kW), the installed heating capacity should be based on the heat required for operation. With 22 kW installed, the actual initial heating time will be less than 3 hours.

Suggested Equipment — Moisture resistant terminal enclosures are recommended for industrial liquid heating applications. Install two stock 12 kW MT-2120E2 or 12 kW MT-3120E2 screw plug heaters or two 12 kW KTLC-312A over-the-side heaters with an automatic temperature control. Automatic temperature control will limit the kWh consumption to actual requirements during operation. A low water level cutoff control is also recommended.

Technical Information

Determining Heat Energy Requirements

Flow Through Water Heating

Circulation heater applications frequently involve “flow through” heating with no recirculation of the heated media. These applications have virtually no start-up requirements. The equation shown below can be used to determine the kilowatts required for most “flow through” applications. The maximum flow rate of the heated medium, the minimum temperature at the heater inlet and the maximum desired outlet temperature are always used in these calculations. A 20% safety factor is recommended to allow for heat losses from jacket and piping, voltage variations and variations in flow rate.

$$Q = \frac{F \times C_p \times \Delta T \times SF}{3412 \text{ Btu/kW}}$$

Where:
Q = Power in kilowatts
F = Flow rate in lbs/hr
C_p = Specific heat in Btu/lb/°F
ΔT = Temperature rise in °F
SF = Safety Factor

Example — Heat 5 gpm of water from 70 - 115°F in a single pass through a circulation heater.

Step 1 — Determine flow rate in lbs/hr.
(Density of water is 8.35 lbs/gal)
5 gpm x 8.35 lbs/gal x 60 min = 2505 lbs/hr

Step 2 — Calculate kW:
C_p = Specific heat of water = 1 Btu/lb/°F

$$\text{kW} = \frac{2505 \text{ lbs} \times 1 \text{ Btu/lb/°F} \times (115-70\text{°F})}{3412 \text{ Btu/kW}} \times 1.2 \text{ SF}$$

kW= 39.6 kW

Temperature Rise Vs. Water Flow[1]

Temp. Rise (°F)	Heater Rating (kW)						
	6	9	12	15	18	24	30
	Flow rate in GPH for given Temperature Rise						
20	122	184	245	306	368	490	613
30	81	122	163	204	245	327	409
40	61	92	122	153	184	245	306
50	49	73	98	122	147	196	245
60	40	61	81	102	122	163	204
70	35	52	70	87	105	140	175
80	30	46	61	76	92	122	153
90	27	40	54	68	81	109	136
100	24	36	49	61	73	98	122
110	22	33	44	55	66	89	111
120	20	30	40	51	61	81	102
130	18	28	37	47	56	75	94

[1] Safety Factor and losses not included.

Flow Through Oil Heating

Oil Heating with Circulation Heaters — The procedure for calculating the requirements for “flow through” oil heating with circulation heaters is similar to water heating. The weight of the liquid being heated is factored by the specific gravity of oil. The specific gravity of a particular oil can be determined from the charts on properties of materials or can be calculated from the weight per cubic foot relative to water.

Example — Heat 3 gpm of #4 fuel oil with a weight of approximately 56 lbs/ft^3 from 50°F to 100°F.

Step 1 — Determine flow rate in lbs/hr.
Specific gravity = 56 lbs/ft^3 ÷ 62.4 lbs/ft^3 = 0.9
3 gpm x 8.35 lbs/gal x 0.9 x 60 min = 1353 lbs/hr

Step 2 — Calculate kW:
Specific heat of fuel oil is 0.42 Btu/lb/°F

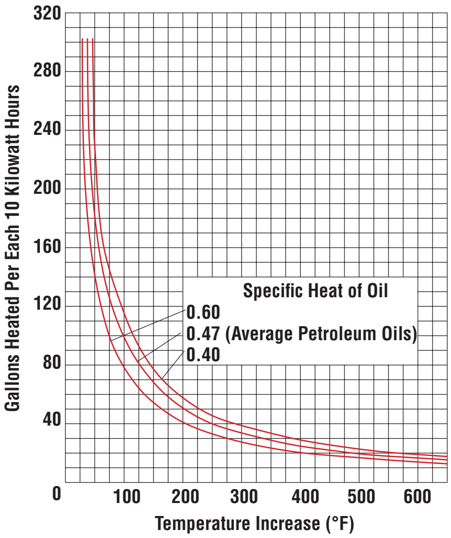
$$\text{kW} = \frac{1353 \text{ lbs} \times 0.42 \text{ Btu/lb/°F} \times (100 - 50\text{°F})}{3412 \text{ Btu/kW}} \times 1.2 \text{ SF}$$

kW = 9.99

Suggestion — Choose watt density for fuel oil and then select heater. Use a stock NWHOR-05-015P, 10 kW circulation heater with an AR-215 thermostat.

Graph G-236 — Oil Heating

Heat Required for Various Temperature Rise (Exclusive of Losses)



CAUTION — Consult recommendations elsewhere in this section for watt density and maximum sheath temperatures for oil heating.

Heating Soft Metal with Melting Pots or Crucibles

Most soft metal heating applications involve the use of externally heated melting pots or crucibles. The following example represents a typical soft metal application.

A steel melting pot weighing 150 lbs contains 400 lbs of lead. The pot is insulated with 2 inches of rock wool and has an outside steel shell with 20 ft^2 of surface area. The top surface of the lead has 3 ft^2 exposed to the air. Determine the kilo-watts required to raise the material and container from 70°F to 800°F in one hour, and heat 250 lbs of lead per hour (70°F to 800°F) thereafter.

Melting point of lead = 621°F
Specific heat of solid lead = 0.0306 Btu/lb/°F
Specific heat of molten lead = 0.038 Btu/lb/°F
Heat of fusion/lead = 10.8 Btu/lb
Specific heat of steel crucible = 0.12 Btu/lb/°F
Radiation loss from molten lead surface = 1000 W/ft^2 (from curve G-128S).
Surface loss from outside shell of pot 62 W/ft^2 (from curve G-126S).
SF = Safety Factor 20%

To Find Start-Up Heating Requirements —

$$Q_T = \left(\frac{Q_A + Q_F + Q_L + Q_C}{t} + \frac{Q_{LS}}{2}\right)(1 + SF)$$

Where:
Q_A = kW to heat lead to melting point. [400 lbs x 0.0306 Btu/lb/°F (621 - 70°F)] ÷ 3412
Q_F = kW to melt lead (400 lbs x 10.8 Btu/lb) ÷ 3412
Q_L = kW to heat lead from melting pt. to 800°F [400 lbs x 0.038 Btu/lb/°F (800 - 621°F)] ÷ 3412
Q_C = kW to heat steel pot [150 lbs x 0.12 Btu/lb/°F (800 - 70°F)] ÷ 3412
Q_{LS} = Surface losses from lead and outside shell [(1000 W x 3 ft^2) + (62 W x 20 ft^2)]/2 ÷ 1000
t = 1 hour
Q_T = 9.98 kW x 1.2 = 11.99 kW

To Find Operating Requirements —

$$Q_T = (Q_A + Q_F + Q_L + Q_{LS})(1 + SF)$$

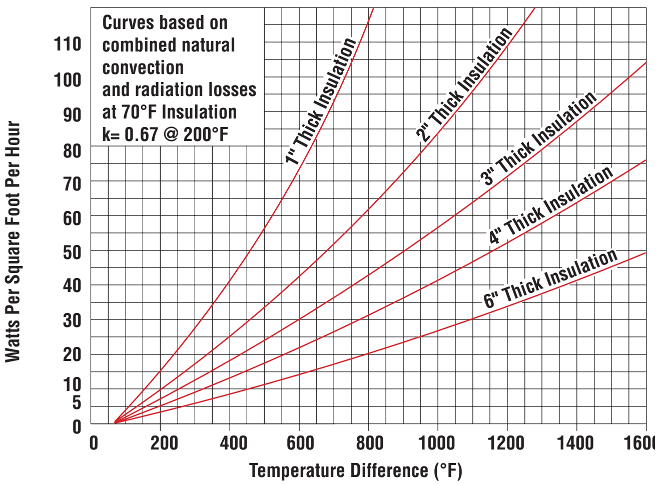
Where:
Q_A = kW to heat added lead to melting point. (250 lbs x 0.0306 Btu/lb/°F [621 - 70°F]) ÷ 3412
Q_F = kW to melt added lead (250 lbs x 10.8 Btu/lb) ÷ 3412
Q_L = kW to heat lead from melting pt. to 800°F (250 lbs x 0.038 Btu/lb/°F [800 - 621°F]) ÷ 3412
Q_{LS} = Surface losses from lead and outside shell (1000W x 3 ft^2) + (62W x 20 ft^2) ÷ 1000
Q_T = 6.69 kW x 1.2 = 8.03 kW

Since start-up requirements exceed the operating requirements, 12 kW should be installed.

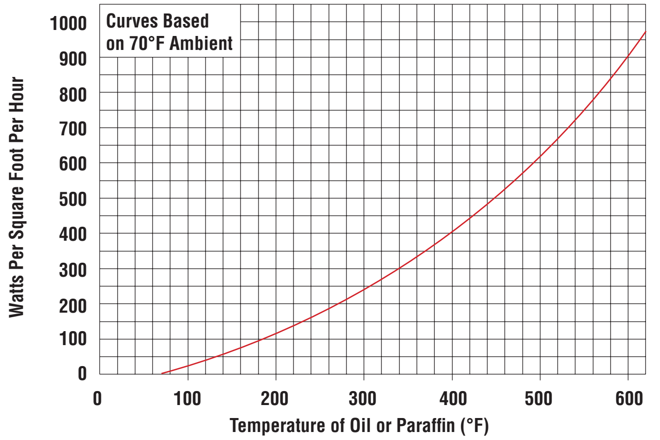
Technical Information

Heat Loss Factors & Graphs

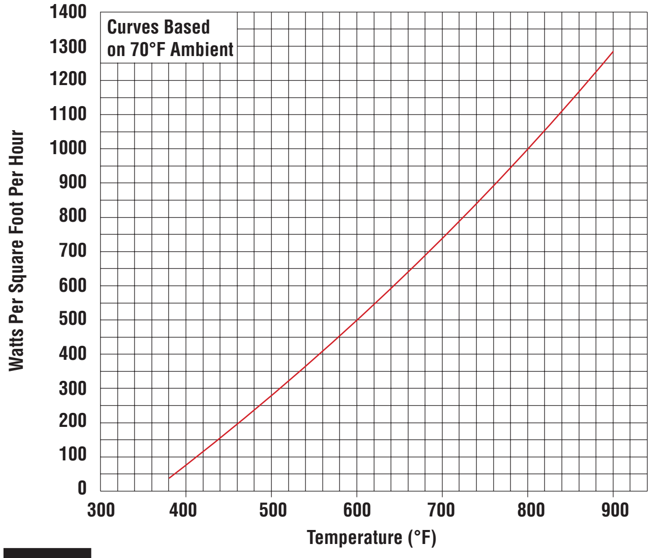
Graph G-126S — Heat Losses from Surfaces of Insulat Walls of Ovens, Pipes, Tanks, Etc.



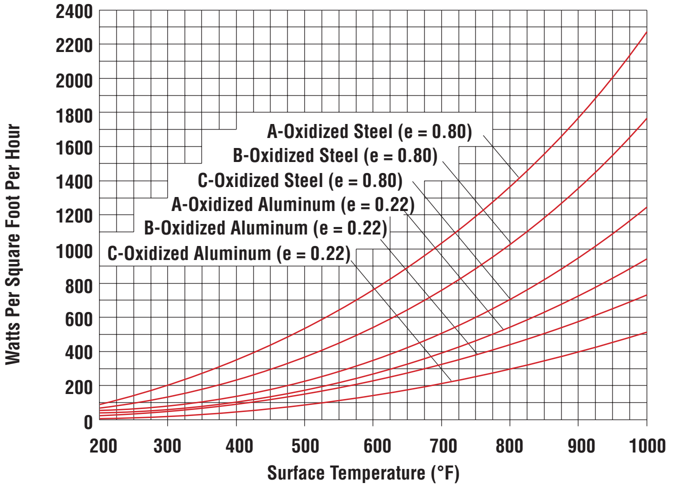
Graph G-127S — Heat Losses from Oil or Paraffin Surfaces



Graph G-128S — Heat Losses from Molten Metal Surfaces (Lead, Babbit, Tin, Type Metal, Solder, Etc.)



Graph G-125S — Heat Losses from Uninsulated Metal Surfaces Combined Losses from Convection & Radiation



Curve A shows heat loss from vertical surfaces of tanks, pipes, etc. and the top of a flat horizontal surface.

Curve B shows the combined heat loss from both the top and bottom surfaces of flat horizontal surfaces.

Curve C shows heat losses from only the bottom surface of flat horizontal surfaces.

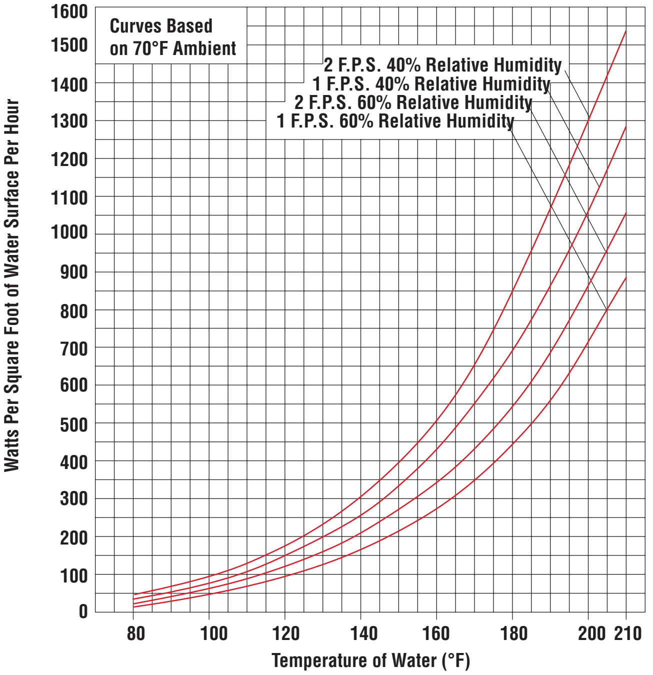
All Curves based on still air (1 fps) @ 70°F, e = emissivity.

Note — The above graph is difficult to read for surface temperatures below 250°F. To estimate heat losses for surface temperatures below 250°F, and the air is still, use the following formula:

$$0.6 \text{ W x ft}^2 \text{ x } \Delta T \text{ °F}$$

Where:
ΔT is the temperature difference in °F between the heated surface and the ambient.

Graph G-114S — Heat Losses from Water Surfaces



Technical Information

Determining Heat Energy Requirements

Pipe & Tank Tracing

The following tables can be used to determine the heat losses from insulated pipes and tanks for heat tracing applications. To use these tables, determine the following design factors:

- Temperature differential $\Delta T = T_M - T_A$
  Where:
  T_M = Desired maintenance temperature °F
  T_A = Minimum expected ambient temperature °F
- Type and thickness of insulation
- Diameter of pipe or surface area of tank
- Outdoor or indoor application
- Maximum expected wind velocity (if outdoors).

Pipe Tracing Example — Maintain a 1-1/2 inch IPS pipe at 100°F to keep a process fluid flowing. The pipe is located outdoors and is insulated with 2 inch thick Fiberglas® insulation. The minimum expected ambient temperature is 0°F and the maximum expected wind velocity is 35 mph. Determine heat losses per foot of pipe.

1. **Heat Loss Rate —** Using Table 1, determine the heat loss rate in W/ft of pipe per °F temperature differential. Enter table with insulation ID or IPS pipe size (1-1/2 in.) and insulation thickness (2 in.).
   Rate = 0.038 Watts/ft/°F.

2. **Heat Loss per Foot —** Calculated heat loss per foot of pipe equals the maximum temperature differential (ΔT) times heat loss rate in Watts/ft/°F.

   ΔT = 100°F - 0°F = 100°F
   Q = (ΔT)(heat loss rate per °F)
   Q = (100°F) (0.038 W/ft) = 3.80 W/ft

3. **Insulation Factor —** Table 1 is based on Fiberglas® insulation and a 50°F ΔT. Adjust Q for thermal conductivity (k factor) and temperature as necessary, using adjustment factors from Table 2.

   Adjusted Q = (Q)(1.08) = 3.80 W/ft x 1.08
   Q = 4.10 W/ft

4. **Wind Factor —** Table 1 is based on 20 mph wind velocity. Adjust Q for wind velocity as necessary by adding 5% for each 5 mph over 20 mph. Do not add more than 15% regardless of wind speed.

   Adjusted Q = (Q)(1.15) = 4.10 W/ft x 1.15
   Design heat loss per linear foot
   Q = 4.72 W/ft

Note — For indoor installations, multiply Q by 0.9.

Table 1 — Heat Losses from Insulated Metal Pipes (Watts per foot of pipe per °F temperature differential [1])

Pipe Size (IPS)	Insul. I.D. (In.)	Insulation Thickness (In.) 1/2	3/4	1	1-1/2	2	2-1/2	3	4
1/2	0.840	0.054	0.041	0.035	0.028	0.024	0.022	0.020	0.018
3/4	1.050	0.063	0.048	0.040	0.031	0.027	0.024	0.022	0.020
1	1.315	0.075	0.055	0.046	0.036	0.030	0.027	0.025	0.022
1-1/4	1.660	0.090	0.066	0.053	0.041	0.034	0.030	0.028	0.024
1-1/2	1.990	0.104	0.075	0.061	0.046	0.038	0.034	0.030	0.026
2	2.375	0.120	0.086	0.069	0.052	0.043	0.037	0.033	0.029
2-1/2	2.875	0.141	0.101	0.080	0.059	0.048	0.042	0.037	0.032
3	3.500	0.168	0.118	0.093	0.068	0.055	0.048	0.042	0.035
3-1/2	4.000	0.189	0.133	0.104	0.075	0.061	0.052	0.046	0.038
4	4.500	0.210	0.147	0.115	0.083	0.066	0.056	0.050	0.041
—	5.000	0.231	0.161	0.125	0.090	0.072	0.061	0.054	0.044
5	5.563	0.255	0.177	0.137	0.098	0.078	0.066	0.058	0.047
6	6.625	0.300	0.207	0.160	0.113	0.089	0.075	0.065	0.053
—	7.625	0.342	0.235	0.181	0.127	0.100	0.084	0.073	0.059
8	8.625	0.385	0.263	0.202	0.141	0.111	0.092	0.080	0.064
—	9.625	0.427	0.291	0.224	0.156	0.121	0.101	0.087	0.070
10	10.75	0.474	0.323	0.247	0.171	0.133	0.110	0.095	0.076
12	12.75	0.559	0.379	0.290	0.200	0.155	0.128	0.109	0.087
14	14.00	0.612	0.415	0.316	0.217	0.168	0.138	0.118	0.093
16	16.00	0.696	0.471	0.358	0.246	0.189	0.155	0.133	0.104
18	18.00	0.781	0.527	0.401	0.274	0.210	0.172	0.147	0.115
20	20.00	0.865	0.584	0.443	0.302	0.231	0.189	0.161	0.125
24	24.00	1.034	0.696	0.527	0.358	0.274	0.223	0.189	0.147

1. Values in Table 1 are based on a pipe temperature of 50°F, an ambient of 0°F, a wind velocity of 20 mph and a "k" factor of 0.25 (Fiberglas®). Values are calculated using the following formula plus a 10% safety margin:
   Watts/ft of pipe = $2 \pi k (\Delta T) \div (Z) \ln (D_0/D_1)$
   Where: k = Thermal conductivity (Btu/in./hr/ft²/°F)
   ΔT = Temperature differential (°F)
   D_0 = Outside diameter of insulation (in.)
   D_1 = Inside dia. of insulation (in.)
   Z = 40.944 Btu/in/W/hr/ft
   In = Natural Log of D_0/D_1 Quotient

Table 2 — Thermal Conductivity (k) Factor of Typical Pipe Insulation Materials (Btu/in./hr/ft²/°F)

Insulation Type		Pipe Maintenance Temperature (°F) 0	50	100	150	200	300	400	500
Fiberglas® or Mineral Fiber Based on ASTM C-547	k value	0.23	0.25	0.27	0.30	0.32	0.37	0.41	0.45
	Adjustment factor	(0.92)	(1.00)	(1.08)	(1.20)	(1.28)	(1.48)	(1.64)	(1.80)
Calcium Silicate[2] Based on ASTMC-533	k value	0.35	0.37	0.40	0.43	0.45	0.50	0.55	0.60
	Adjustment factor	(1.52)	(1.48)	(1.60)	(1.72)	(1.80)	(2.00)	(2.20)	(2.40)
Foamed Glass[2] Based on ASTMC-552	k value	0.38	0.40	0.43	0.47	0.51	0.60	0.70	0.81
	Adjustment factor	(1.52)	(1.60)	(1.72)	(1.88)	(2.04)	(2.40)	(2.8)	(3.24)
Foamed Urethane Based on ASTMC-591	k value	0.18	0.17	0.18	0.21	0.25	Not Recommended		
	Adjustment factor	(0.72)	(0.68)	(0.72)	(0.84)	(1.00)			

2. When using rigid insulation, select an inside diameter one size larger than the pipe on pipe sizes through 9 in. IPS. Over 9 in. IPS, use same size insulation.

Table 3 — Heat Losses from Insulated Metal Tanks (W/ft²/°F)[3]

Insulation Thickness (In.) 1/2	3/4	1	1-1/2	2	2-1/2	3	3-1/2	4	5	6
0.161	0.107	0.081	0.054	0.040	0.032	0.027	0.023	0.020	0.016	0.013

3. Values in Table 3 are based on a tank temperature of 50°F, an ambient of 0°F, a wind velocity of 20 mph and a "k" factor of 0.25 (Fiberglas®). Values are calculated using the following formula plus a 10% safety margin:
   Watts/ft² = $Y k(\Delta T) \div X$
   Where: Y = 0.293W/hr/btu
   k = Thermal conductivity
   X = Thickness of insulation (in.)
   Δ = Temperature differential (°F)

Note — The above information is presented as a guide for solving typical heat tracing applications. Contact your Local Chromalox Sales office for assistance in heater selection and for pipes made of materials other than metal.

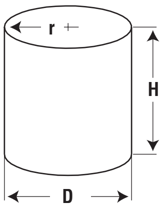
Technical Information

Determining Heat Energy Requirements

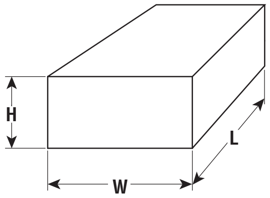
Pipe & Tank Tracing (cont'd.)

Tank tracing requires an additional calculation of the total exposed surface area. To calculate the surface area:

Cylindrical Tanks —
Area = $2 \pi r^2 + \pi DH$
$A = \pi D (r + H)$



Horizontal Tanks —
Area = $2[(W \times L) + (L \times H) + (H \times W)]$



Tank Tracing Example — Maintain a metal tank with 2 inch thick Fiberglas® insulation at 50°F. The tank is located outdoors, is 4 feet in diameter, 12 feet long and is exposed at both ends. The minimum ambient temperature is 0°F and the maximum expected wind speed is 15 mph.

1. **Surface Area** — Calculate the surface area of the tank.
   $A = \pi D (r + H)$
   $A = \pi 4 (2 + 12)$
   $A = 175.9 \text{ ft}^2$
2. **Temperature Differential** (ΔT)

   $\Delta T = T_M - T_A = 50°\text{F} - 0°\text{F} = 50°\text{F}$
3. **Heat Loss Per Foot^2** — Obtain the heat loss per square foot per degree from Table 3.

   Heat loss/ft^2/°F = 0.04 W/ft^2/°F
4. **Insulation Factor** — Table 3 is based on Fiberglas® insulation and a 50°F ΔT. Adjust Q for thermal conductivity (k factor) and temperature as necessary, using factors from Table 2.
5. **Wind Factor** — Table 3 is based on 20 mph wind velocity. Adjust Q for wind velocity as necessary, by adding 5% for each 5 mph over 20 mph. Do not add more than 15% regardless of wind speed. **Note** — For indoor installations, multiply Q by 0.9.
6. **Calculate Total Heat Loss for Tank** — Multiply the adjusted heat loss per square foot per °F figure by the temperature differential. Multiply the loss per square foot by the area.

   $Q = 0.04 \text{ W/ft}^2/°\text{F} \times 50°\text{F } \Delta T = 2 \text{ W/ft}^2$
   Q = Adjusted W/ft^2 x tank surface area
   $Q = 2 \text{ W/ft}^2 \times 175.9 \text{ ft}^2$

   Heat Loss from Tank = 351.8 Watts

Comfort Heating

For complete building and space heating applications, it is recommended that a detailed analysis of the building construction heat losses (walls, ceilings, floors, windows, etc.) be performed using ASHRAE guidelines. This is the most accurate and cost effective estimating procedure. However, a quick estimate of the kW requirements for room and supplemental heating or freeze protection can be obtained using the chart to the right.

Problem — A warehouse extension measures 20 ft long x 13 ft wide x 9 ft high. The building is not insulated. Construction is bare concrete block walls and an open ceiling with a plywood deck and built-up roof. Determine the kW required to maintain the warehouse at 70°F when the outside temperature is 0°F.

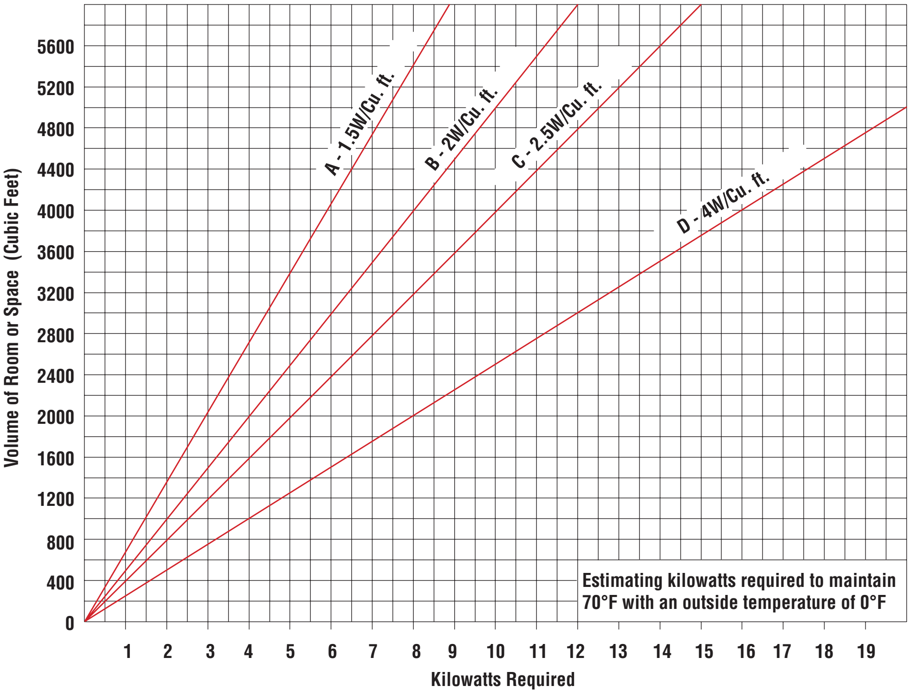
Solution —

1. **Calculate** the volume of the room.

   $20 \text{ ft} \times 13 \text{ ft} \times 9 \text{ ft} = 2{,}340 \text{ ft}^3$
2. **Refer** to the chart, use Curve D which corresponds to the building construction.
3. **Find** the intersection of 2,340 ft^3 with curve D. The kilowatts required are 9.3 kW. Suggest using a 10 kW unit blower heater.

Note — If the volume of the room is larger than the chart values, divide by 2, 3, 4, etc. until the trial volume fits the curve. Then select heater from this volume. Multiply heaters selected by the number used to select the trial volume.

Comfort Heating Chart



Curve A — Rooms with little or no outside exposure. No roof or floor with outside exposure; only 1 wall exposed with not over 15% door and window area.

Curve B — Rooms with average exposure. Roof and 2 or 3 walls exposed, up to 30% door and window area. But with roof, walls and floor insulated if exposed to outside temperatures.

Curve C — Rooms with roof, walls and floor uninsulated but with inside facing on walls and ceiling.

Curve D — Exposed guard houses, pump houses, cabins and poorly constructed rooms with reasonably tight joints but no insulation. Typical construction of corrugated metal or plywood siding, single layer roofs.

Technical Information

Watt Density & Heater Selection - Guidelines

Understanding Watt Density

Watt density (W/in^2) is the heat flux emanating from each square inch of the effective heating area (heated surface) of the element.

W/in^2 = Rated Watts ÷ Effective heating area

The effective heating area is the surface area per linear inch of the heater multiplied by the heated length. For strip heaters which are rectangular in shape, the surface area per linear inch is:

1-1/2" wide = 3.45 in^2 per linear inch
1" wide = 2.31 in^2 per inch.

The heated length (HL) of strip heaters is calculated as follows:

< 30-1/2" long HL = Overall Length less 4"
≥ 30-1/2" long HL = Overall Length less 5"

For tubular elements, watt density is determined by the following formulas.

Effective heating area = π x Dia. x Heated Length

The surface area per linear inch of standard diameter tubular elements is shown below:

Size (Dia.)	$In^2/in.$
0.246 inch (1/4)	0.77
0.315 inch (5/16)	0.99
0.375 inch (3/8)	1.18
0.430 inch (7/16)	1.35
0.475 inch	1.49
0.500 inch (1/2)	1.57

The following example illustrates the procedure for determining the watt density of a typical tubular heater.
Example — A 12 kW screw plug heater has three 0.475" diameter elements with a "B" dimension of 32 inches and a 2 inch cold end. The watt density is:

0.475 x π x (32 in. - 2 in.) x 3 x 2 (Hairpin) = 268 in^2

12,000 Watts ÷ 268 in^2 - 45 W/in^2

For convenience in selecting equipment, all heaters in this catalog have the watt density specified for standard ratings.

Heater Selection Guidelines

Once the total heat energy requirements have been determined, the selection of the type of electric heater is based on three criteria.

- Maximum Sheath Temperature
- Sheath Material
- Recommended Maximum Watt Density

Maximum Sheath Temperature — The sheath temperature of an electric element should be limited to prevent damage to the heater and provide reasonable life. To a large extent, the maximum sheath temperature of the heating element is determined by the final operating temperature of the process. In direct immersion applications, the sheath temperature will approximate the temperature of the heated media. In clamp-on, air and gas heating applications, the operating sheath temperature can be estimated using factors derived from empirical charts and graphs.

Sheath Material — Element sheath material is selected based on the maximum allowable sheath temperature, the material being heated and corrosion resistance required. Depending on the sheath material and construction, metal sheathed electric resistance elements will operate satisfactorily at temperatures from less than -300°F (cryogenic) to approximately 1500°F. Copper sheath elements are commonly used for low temperature and direct immersion water heating. Steel is used for oil immersion and strip heater applications. Stainless steel and INCOLOY® are used for corrosive solutions, high-temperature gas or air heating and cartridge heaters. The table below lists the maximum recommended operating temperatures for common sheath materials (UL 1030):

Copper	350°F	Chrome Steel	1200°F
Iron	750°F	Stainless 300	1200°F
Steel	750°F	INCOLOY®	1600°F[1]
MONEL®	900°F	INCONEL®	1700°F[1]

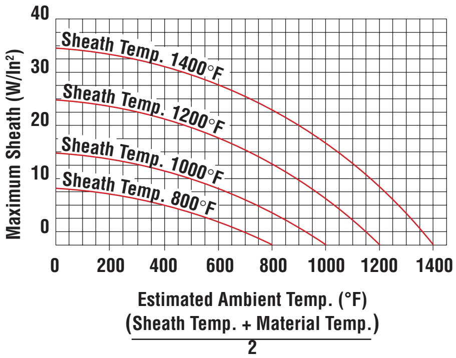
Maximum Recommended Watt Density — Some materials such as water, vegetable oils and salt baths can tolerate relatively high sheath watt densities. Other materials such as petroleum oils or sugar syrups require lower watt densities. These solutions have high viscosity and poor thermal conductivity. If the watt density is too high, the material will carbonize or overheat, resulting in damage to the heating equipment or material being heated. Other sections of this catalog provide guidelines and suggestions for sheath materials and recommended watt densities for many common heating problems.

Using the values determined in the selection criteria, choose the type of heater best suited to the application. For instance, water can be heated by direct immersion, circulation heaters or with tubular or strip heaters clamped to tank walls. The final choice of heater type will involve process considerations, appearance, available space both inside and outside, economy, maintenance, etc. The following pages cover the procedures for selecting heaters for clamp-on applications, liquid immersion heating, oil immersion heating, air or gas heating and cartridge or platen heating.

Clamp-On Heater Applications

The limiting factor in most clamp-on heater applications is the operating temperature of the heater sheath. Selecting heaters for clamp on applications requires an analysis of the maximum expected sheath temperature based on the estimated ambient temperature and the temperature of the material being heated. Graph G-175S provides a method of estimating the sheath temperature and allowable watt densities for tubular heaters for various ambient temperatures and wattage ratings.

Graph G-175S — Clamp-On Tubular Heaters



The example on the following page illustrates the procedure. 12 kW is required to heat material in a steel tank from 70°F to 800°F. Heat is to be supplied by tubular electric elements clamped to the side of the tank. Since the material is heated to 800°F, INCOLOY® sheath elements must be used.

Note 1 — For sheath temperatures above 1500°F, contact your Local Chromalox Sales office for application assistance.

Technical Information

Allowable Watt Density & Heater Selection - Guidelines

Selecting Clamp-On Tubular Heaters (cont'd.)

From the chart, a maximum sheath temperature of 1200°F results in an average ambient temperature of (800°F + 1200°F) ÷ 2 = 1000°F. From the curves, the allowable watt density is 9.5 W/in^2. Based on size of container, 0.475 inch diameter TRI elements 28 in. long are selected.

The 0.475 TRI element has 1.49 in^2 per linear inch of sheath. The heated length is the overall sheath length less 6.5 inches. The allowable wattage rating on the element is (28 - 6.5) x 1.49 x 9.5 = 305 watts. The total number of elements required is 12,000W ÷ 305W = 39 elements. Order 39 elements similar to TRI-2845 except rated 305 watts. If the application requires the use of tubular elements whose overall length is not standard, each element rating would be determined as follows:

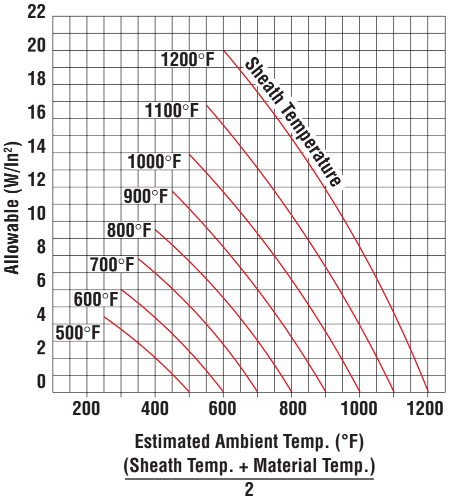
Heater Watts = (*A* - 2CE) (*Area* x 9.5W)

Where:
A = Sheath length, overall
CE = Cold pin length
Area = Effective heated area (in^2/in.)
9.5 = recommended W/in^2 from G-175S

Selecting Clamp-On Strips Heaters

Graph G-130S provides a method of estimating the maximum allowable watt density for strip heaters for clamp on applications based on sheath operating temperature and various ambients.

Graph G-130S — Clamp-On Strip Heaters



Using the previous 12 kW example, determine the number of strip heaters required. An 800°F material temperature requires chrome steel strip heaters. From Graph G-130S, a maximum sheath temperature of 1200°F results in an ambient temperature of 1000°F inside the space between the thermal insulation and the vessel, (800°F + 1200°F) ÷ 2 = 1000°F.

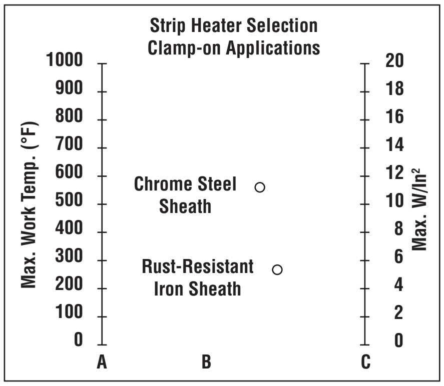
From the curve, the allowable watt density is 8 W/in^2. Based on the tank size, chrome steel sheathed strip heaters 24 inches long without mounting tabs were selected. To determine the number and wattage of strip heaters needed, use the formula: allowable watts per strip = (overall length minus 4" cold section) x 3.45 in^2 per lineal inch of sheath x 8 watts/in^2. Thus (25-1/2" - 4") x 3.45 x 8 = 593 (600) watts. The total number of strips required is 12,000W ÷ 600W = 20 strips. Order strips similar to OT-2507 in size but rated 600 watts. To avoid a special order, consider using 24 standard OT-2405, 500 watt strips. These heaters would have a watt density of:

500W ÷ ([23-3/4 - 4] x 3.45) = 7.35 W/in^2

If the application uses 3 phase power, the total element count should be a multiple of 3 to permit a balanced electrical load.

The nomograph below may also be used for heater selection in clamp-on strip heating applications.

Strip Heater Nomograph



To Use the Graph —

1. **Select** the maximum desired work temperature on A.
2. **Choose** either chrome steel or rust-resistant iron sheath (points B) on the basis of operating temperatures.
3. **Draw** a straight line through points A and B to C. C gives the maximum allowable watts per square inch.
4. **Select** desired length heater with equivalent or less watt density.

General Recommendations for Liquid Heating Applications

Chromalox standard immersion heater ratings match the suggested watt densities for general purpose immersion heating. Extended heater life will be obtained by using the lowest watt density practical for any given application.

Standard Ratings —

Water Heaters	45 - 75 W/in^2
Corrosive Solution Heaters	20 - 23 W/in^2
Oil Heaters (Light Wt.)	20 - 23 W/in^2
Oil Heaters (Medium Wt.)	15 W/in^2
Oil Heaters (Heavy Wt.)	6 - 10 W/in^2

Suggested Allowable Watt Densities for Liquids

Material	Max. Temp (°F)	Max. W/In^2
Acid solutions	180	40
Alkaline solutions (Oakite)	212	40
Asphalt, tar, and other heavy or highly viscous compounds	200 300 400 500	10 8 7 6
Bunker C fuel oil	160	10
Caustic soda 2% 10% 75%	210 210 180	45 25 15
Dowtherm® A	750	23
Dowtherm® A vaporizing	750	10
Dowtherm® J liquid	575	23
Electroplating tanks	180	40
Ethylene glycol	300	30
Freon	300	3
Fuel oil pre-heating	180	9
Gasoline, kerosene	300	20-23
Machine oil, SAE 30	250	18-20
Metal melting pot	500-900	20-27
Mineral oil	200 400	20-23 16
Molasses	100	4-5
Molten salt bath	800-950	25-30
Molten tin	600	20-23
Oil draw bath	400 600	20-23 16
Steel cast into aluminum	500-750	50
Steel cast into iron	750-1000	55
Heat transfer oils (Therminol®, Mobiltherm®, etc.)	500-650	23
Vapor degreasing solutions	275	20-23
Vegetable oil (fry kettle)	400	20-30
Water (process)	212	40-75
Water (washroom)	140	75-100

Note — The above watt densities are based on non-circulating liquids. The allowable watt density may be adjusted when heat transfer or flow rates are increased.

Technical Information

Heater Selection - Oil Heating

Watt Density & Oil Viscosity

The viscosity of oils and hydrocarbons varies widely with type and temperature. Since highly viscous liquids transfer heat poorly, sheath watt densities and operating temperatures are critical in oil heating applications. As a general rule, regular oil heaters rated 20-23 W/in^2 are recommended for heating light weight oils (SAE 10 to SAE 30). For medium weight oils (gear oils, etc.), 12-15 W/in^2 are suggested. Bunker C, tar, asphalt and other highly viscous oils may require 6-8 W/in^2 or less to prevent carbonization, particularly if not under flowing conditions. Some oils may have additives that will boil off or carbonize at very low watt densities. When oils of this type are encountered, a watt density test is recommended to determine a satisfactory watt density. The following charts provide guidance and suggested watt densities for various oils.

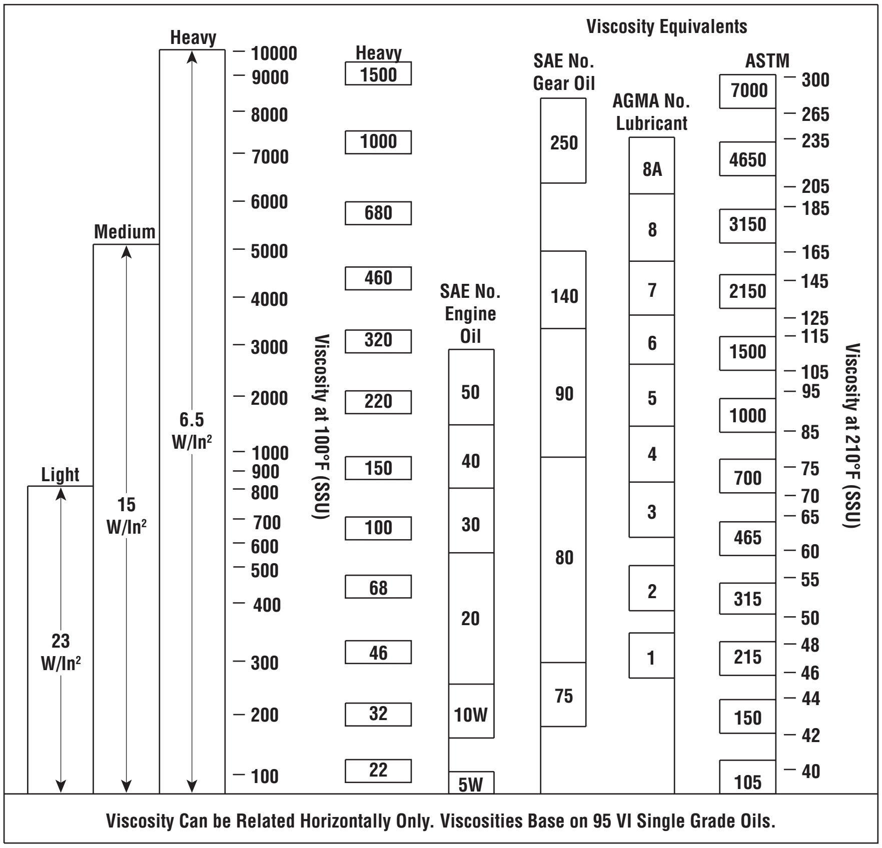
Typical Viscosities of Various Oils

Weight	Viscosity
SAE 10	90-120 SSU at 130°F
SAE 20	120-185 SSU at 130°F
SAE 30	185-255 SSU at 130°F
SAE 40	255 SSU-up (Drops to 80 at 210°F)
SAE 50	80-105 SSU at 210°F
#2 Fuel Oil	40 SSU at 100°F (Kerosene)
#4 Fuel Oil	45-120 SSU at 100°F
#5 Fuel Oil	150-400 SSU at 100°F
Bunker C	500-2,000 SSU at 100°F
#6 Fuel Oil	3,000 SSU at 122°F (Very Viscous)

Viscosity Conversion

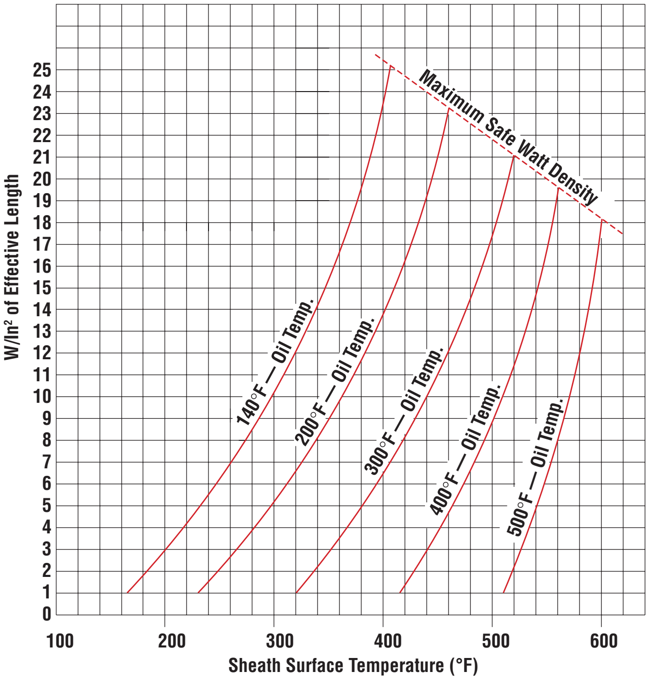
Seconds Saybolt Universal (SSU)	Kinematic Viscosity Centistokes (Cst)	Seconds Saybolt Furol (SSF)
31	1	—
35	2.56	—
40	4.30	—
50	7.4	—
60	10.3	—
70	13.1	12.95
80	15.7	13.7
90	18.2	14.44
100	20.6	15.24
150	32.1	19.3
200	43.2	23.5
250	54	28
500	110	51.6
1,000	220	100.7
5,000	1,100	500
10,000	2,200	1,000
20,000	4,400	2,000

Centistokes = Centipoise/specific gravity
Centipoise x 2.42 = Lbs/ft/hr



Viscosity Can be Related Horizontally Only. Viscosities Base on 95 VI Single Grade Oils.

Graph G-122S — Surface Temperatures of Oil Immersion Blade Heater for Various Oil Temperatures & Watt Densities



Notes —

1. Curves based on natural convection of machine oil or its equivalent having an SAE viscosity rating of 30 (5 centipoises at 200°F).
2. Effective Length of Immersion Heater = "B" Dimension.
3. Area Per Linear Inch of 1-1/2' Wide Immersion Blades = 3.75 Sq. In.
4. Area Per Linear Inch of 1' Wide Immersion Blades = 2.63 Sq. In.
5. In No Case, Exceed 27 Watts Per Sq. In.

Technical Information

Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating

Air and gas heating applications can be divided into two conditions, air or gas at normal atmospheric pressure and air or gas under low to high pressure. Applications at atmospheric pressure include process air, re-circulation and oven heating using duct or high temperature insert air heaters. Pressurized applications include pressurized duct heating and other processes using high pressures and circulation heaters. Procedures for determining heat energy requirements for either condition are similar except the density of the compressed gas and the mass velocity of the flow must be considered in pressurized applications. Selection of equipment in both conditions is critical due to potentially high sheath temperatures that may occur.

Determining Heat Requirements for Atmospheric Pressure Gas Heating

The following formulas can be used to determine kW required to heat air or gas:

Equation A —

$$\text{kW} = \frac{\text{CFM x lbs/ft}^3 \text{ x 60 min x } C_p \text{ x } \Delta T}{\text{3412 Btu/kW}} \text{ x SF}$$

Where:
CFM = Volume in cubic feet per minute
Lbs/ft^3 = Density of air or gas at initial temperature
C_p = Specific heat of air or gas at initial temperature
ΔT = Temperature rise in °F
SF = Suggested Safety Factor

For quick estimates of air heating requirements for inlet temperatures up to 120°F, the following formula can be used.

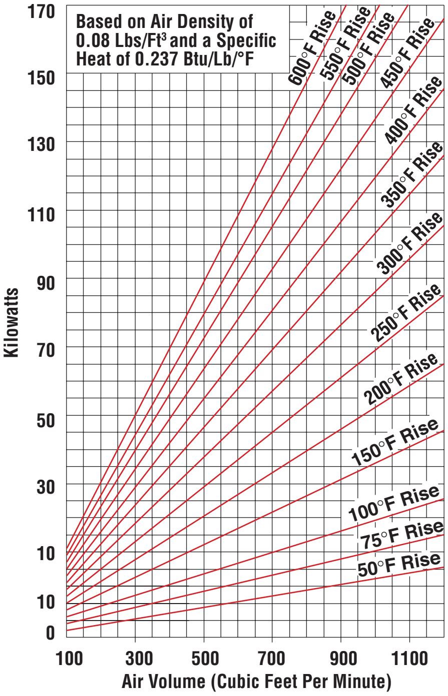
$$\text{kW} = \frac{\text{SCFM x } \Delta T}{3{,}000} \text{ x 1.2 SF}$$

Where:
SCFM = Volume of air in cubic feet per minute at standard conditions[1] (70˚ F at standard atmospheric pressure)
3,000 = Conversion factor for units, time and Btu/lb/°F
1.2 SF = Suggested safety factor of 20%

Graph G-176S — When airflow (ft^3/min) and temperature rise are known, kW requirements can be read directly from graph G-176S.
Note — Safety factors are not included.

Note 1 — Based on an average density of 0.08 lbs/ft^3 and a specific heat of 0.24 Btu/lb/°F. For greater accuracy, use Equation A and values from the Properties of Air Chart in this section.

Graph G-176S —Air Heating



Process Air Heating Calculation Example — A drying process requires heating 450 ACFM of air[1] from 70°F to 150°F. The existing duct- work measures 2 ft wide by 1 ft high and is insulated (negligible losses). To find heating capacity required, use Equation A:

$$\text{kW} = \frac{\text{450 ACFM x 0.08 x 60 x 0.24 x 80}}{\text{3412 Btu/kW}} \text{ x 1.2 SF}$$

kW = 14.58

Heater Selection

Finstrip® (CAB heaters), Fintube® (DH heaters) or tubular elements (TDH, ADH and ADHT heaters) will all work satisfactorily in low temperature applications. Finstrips or finned tubular elements are usually the most cost effective. Tubular elements are recommended for high temperatures. Once the desired type of heating element is selected, the next step is to calculate the air velocity and estimate sheath temperatures to verify that maximum operating temperatures are not exceeded. Calculate the air velocity over the elements and refer to allowable watt density graphs for estimated operating temperature.

Calculating Air Velocity — Air velocity can be calculated from the following formula:

$$\text{Velocity (fps)} = \frac{\text{Flow (ACFM)}}{\text{Area of Heater (ft}^2\text{) x 60 sec.}}$$

Low Temperature Heater Selection — A ypical heater selection for the previous example might be a type CAB heater with finstrip elements. Available 15 kW stock heaters include a CAB-1511 with chrome steel elements or a CAB-152 with iron sheath elements, both rated at 26 W/in^2. From the product page, the face area of a 15 kW CAB heater is 1.19 ft^2:

$$\text{Velocity (fps)} = \frac{\text{450 ACFM}}{\text{1.19 ft}^2 \text{ x 60 sec.}} = \text{6.3 fps}$$

Estimating Sheath Operating Temperature — The maximum operating sheath temperatures for finstrips are 750°F for iron and 950°F for chrome steel. Using graph G-107S for iron sheath finstrips, a 150°F outlet temperature and a watt density of 26 W/in^2 requires a velocity in excess of 9 ft/sec to keep sheath temperatures below maximum permissible levels. With only 6.3 fps in the application, a CAB-152 heater with iron sheath elements is not suitable. Using graph G-108S for chrome sheath finstrips, approximately 3 ft/sec. air velocity results in a maximum of 900°F sheath temperature. Since this is lower than the actual velocity of 6.3 fps, a CAB-1511 with chrome steel finstrips is an acceptable heater selection. (Use graphs G-100S, G-105S,G-106S and G-132S for air heating with regular strip and finstrip heaters.)

High Temperature Heater Selection — Type TDH and ADHT heaters with tubular elements are recommended for high temperature applications. Steel sheath tubulars may be used where the sheath temperature will not exceed 750°F. Finned tubulars can be used in applications up to a maximum sheath temperature of 1050°F. INCOLOY® sheath tubulars may be used for applications with sheath temperatures up to 1600°F. Allowable watt densities for tubulars and finned tubulars can be determined by reference to graphs G-136S and G-151-1 through G-156-1.

Estimating Sheath Operating Temperature — Select a heater for a high temperature application with an inlet air temperature of 975°F and a velocity of 4 ft/sec. Since the temperature is above 750°F, an INCOLOY® sheath must be used. Using graph G-152-1 the allowable watt density is 11 W/in^2 for sheath temperatures of 1200°F or 22 W/in^2 for temperatures of 1400°F. In this application, a stock ADHT heater[2] with a standard watt density of 20 W/in^2 can be used.

Note 2 — Special ADHT duct heaters, derated to the required watt density, can be supplied when element ratings less than the standard 20 W/in^2 are needed.

Technical Information

Allowable Watt Density & Heater Selection - Air Heating

Air & Gas Heating with Strip and Finstrip® Heaters

Custom Designs — Strip and finstrip heaters are frequently mounted in banks by the end user. Graphs G-105S and G-106S on this page can be used in conjunction with other graphs to determine maximum watt density for virtually any custom design low temperature heating application.

Graph G-105S — Strip Heaters
To use this graph:

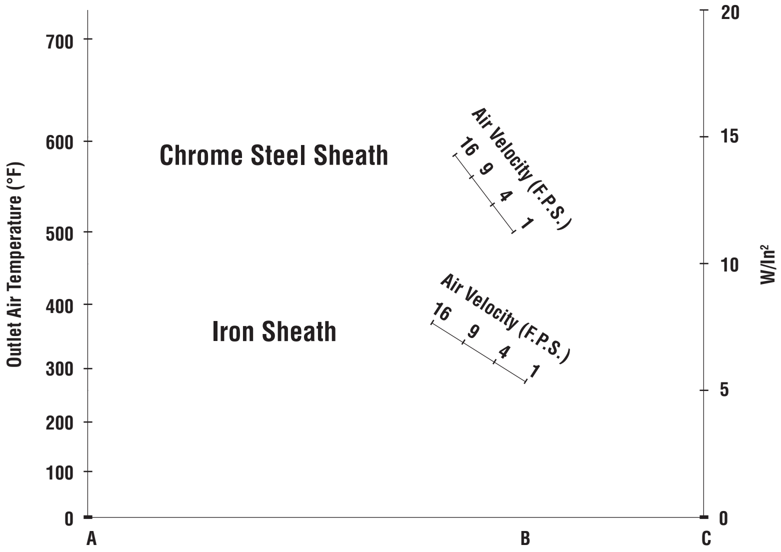
1. **Select** maximum desired outlet air temperature on line A.
2. **Choose** either chrome steel sheath or rust resisting iron sheath (points B) on the basis of operating conditions.
3. **Select** minimum anticipated air velocity on B. **Note** — natural circulation is equal to approximately one foot per second.
4. **Draw** a straight line through points A and B to a reading on C. Read maximum allowable watts per square inch from line C.
5. **Select** desired length heater with an equivalent watt density or less from the product page in this catalog.

Graph G-106S — Finstrip® Heaters
To use this graph:

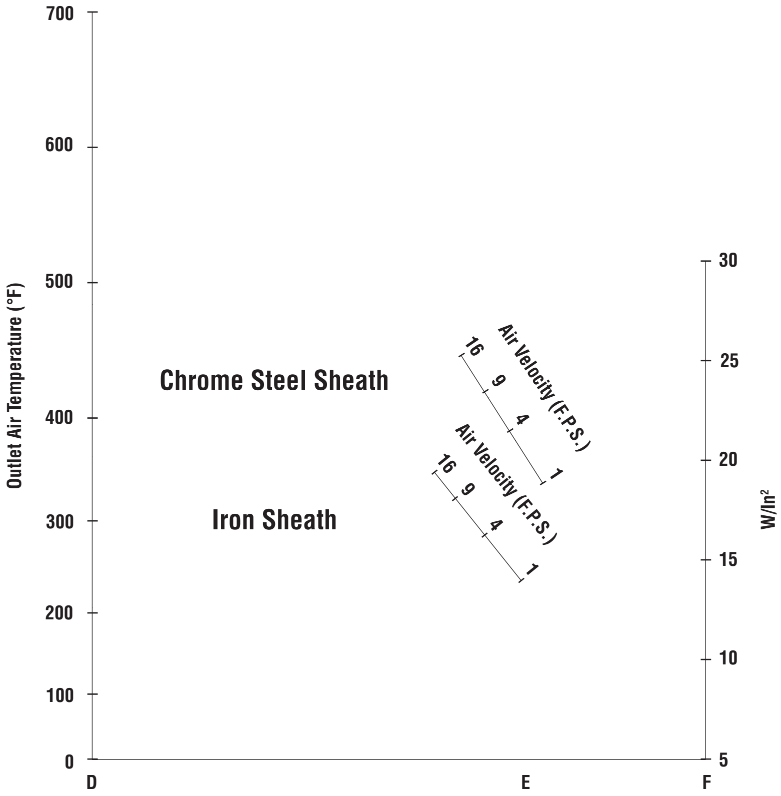
1. **Select** maximum desired outlet air temperature on line D.
2. **Choose** either chrome steel sheath or rust resisting iron sheath (points E) on the basis of operating conditions.
3. **Select** minimum anticipated air velocity on B. **Note** — natural circulation is equal to approximately one foot per second.
4. **Draw** a straight line through points D and E to a reading on F. Read maximum allowable watts per square inch from line F.
5. **Select** desired length heater with an equivalent watt density or less from the product page in this catalog.

Recommendations for Custom Installations — Strip heaters should always be mounted sideways in the ductwork with the narrow edges facing the air stream. The total number of elements installed should be divisible by 3 so that the heater load will be balanced on a three phase circuit.

Graph G-105S — Strip Heater Air Heating-Selection of Watt Density



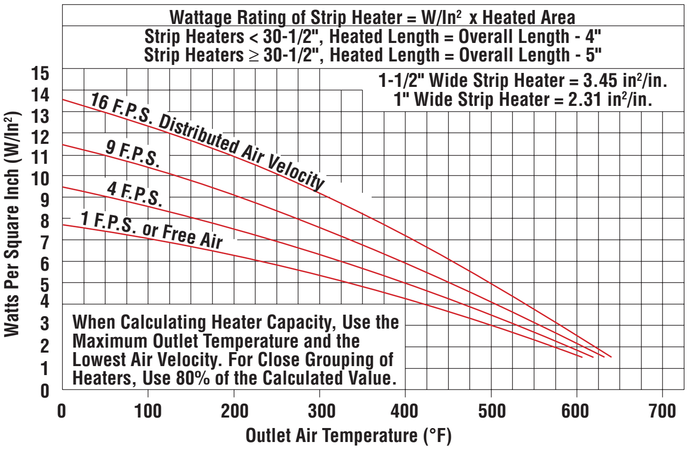
Graph G-106S — Finstrip® Heater Air Heating-Selection of Watt Density



Technical Information

Allowable Watt Density & Heater Selection - Air Heating

Graph G-132S — Strip Heater (Iron) Air Heating Allowable Watt Densities for 700°F Sheath Temp.


Wattage Rating of Strip Heater = W/In² x Heated Area

Strip Heaters < 30-1/2", Heated Length = Overall Length - 4"

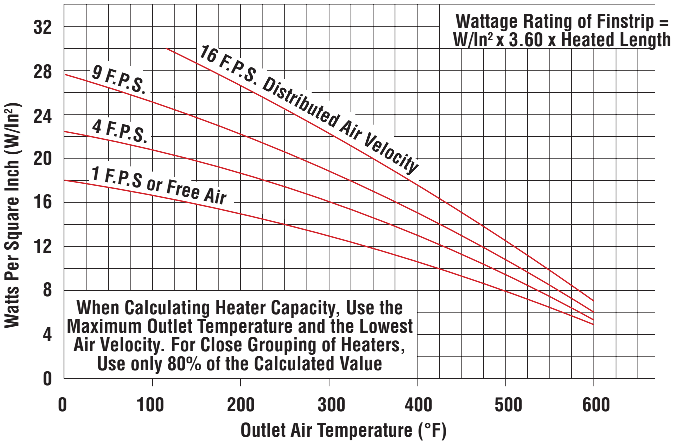
Strip Heaters ≥ 30-1/2", Heated Length = Overall Length - 5"

1-1/2" Wide Strip Heater = 3.45 in²/in.

1" Wide Strip Heater = 2.31 in²/in.

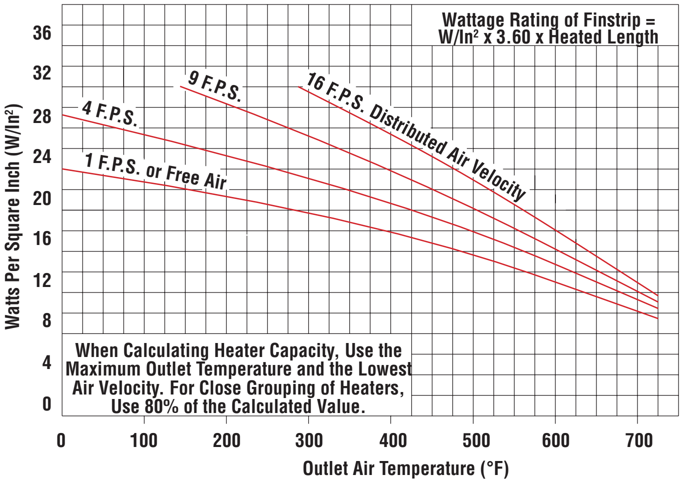
When Calculating Heater Capacity, Use the Maximum Outlet Temperature and the Lowest Air Velocity. For Close Grouping of Heaters, Use 80% of the Calculated Value.

Graph G-107S — Finstrip® (Iron Sheath) Air Heating Allowable Watt Densities for 700°F Sheath Temp.


Wattage Rating of Finstrip = W/In² x 3.60 x Heated Length

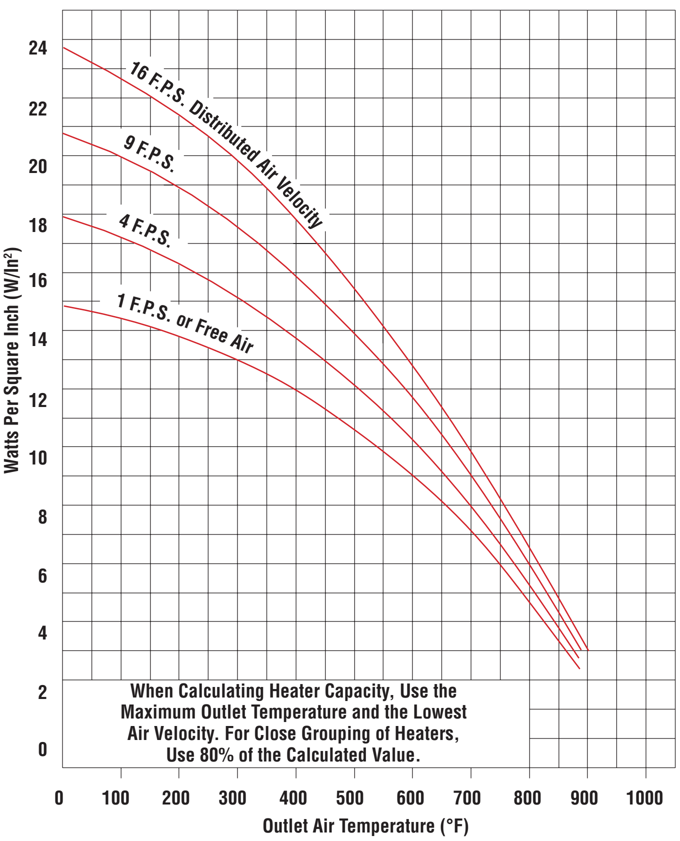
When Calculating Heater Capacity, Use the Maximum Outlet Temperature and the Lowest Air Velocity. For Close Grouping of Heaters, Use only 80% of the Calculated Value

Graph G-108S — Finstrip® (Chrome Steel) Air Heating Allowable Watt Densities for 900°F Sheath Temp.


Wattage Rating of Finstrip = W/In² x 3.60 x Heated Length

When Calculating Heater Capacity, Use the Maximum Outlet Temperature and the Lowest Air Velocity. For Close Grouping of Heaters, Use 80% of the Calculated Value.

Graph G-100S — Strip Heater (Chrome) Air Heating Allowable Watt Densities for 1000°F Sheath Temp.


When Calculating Heater Capacity, Use the Maximum Outlet Temperature and the Lowest Air Velocity. For Close Grouping of Heaters, Use 80% of the Calculated Value.

Notes —

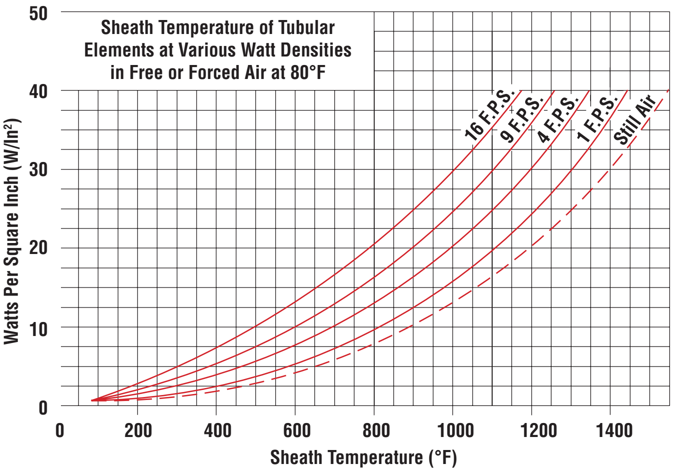
Strip Heaters < 30-1/2", Heated Length = Overall Length - 4"

Strip Heaters ≥ 30-1/2", Heated Length = Overall Length - 5"

1-1/2" Wide Strip Heater = 3.45 in./in.

1" Wide Strip Heater = 2.31 in./in.

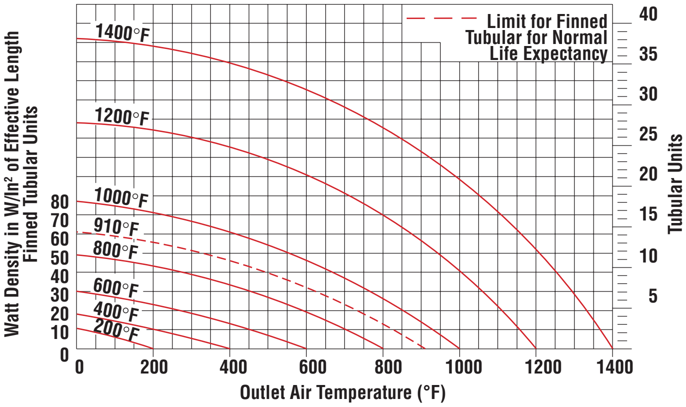
Graph G-136S — Tubular Heater Air Heating


Sheath Temperature of Tubular Elements at Various Watt Densities in Free or Forced Air at 80°F

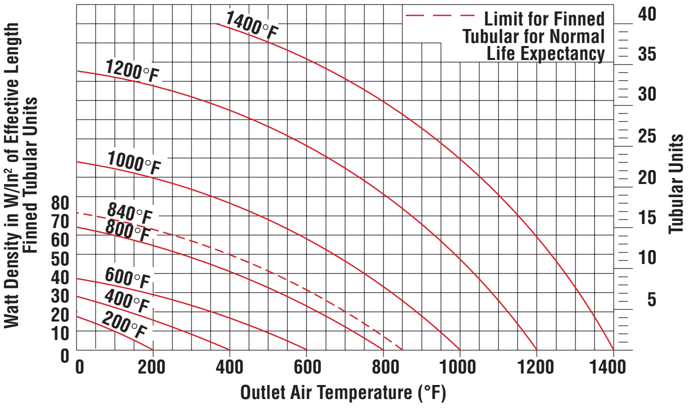
Technical Information

Allowable Watt Density & Heater Selection - Air Heating

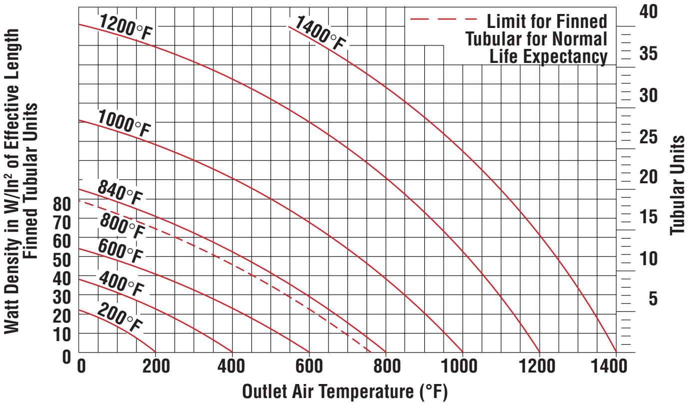
Graph G-151-1 — Fintube® & Tubular Heaters Sheath Temperatures with 1 FPS Distributed Air Velocity



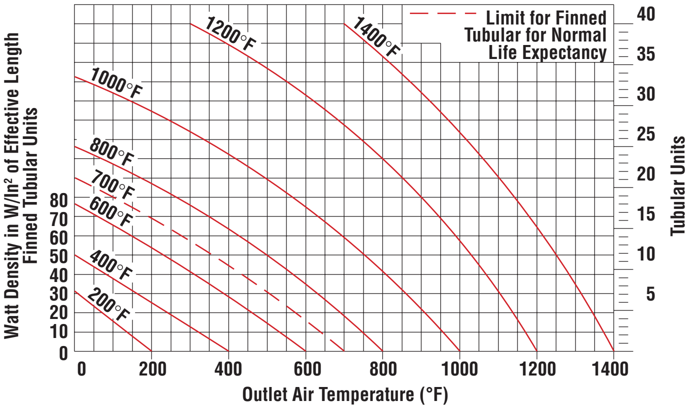
Graph G-152-1 — Fintube® & Tubular Heaters Sheath Temperatures with 4 FPS Distributed Air Velocity



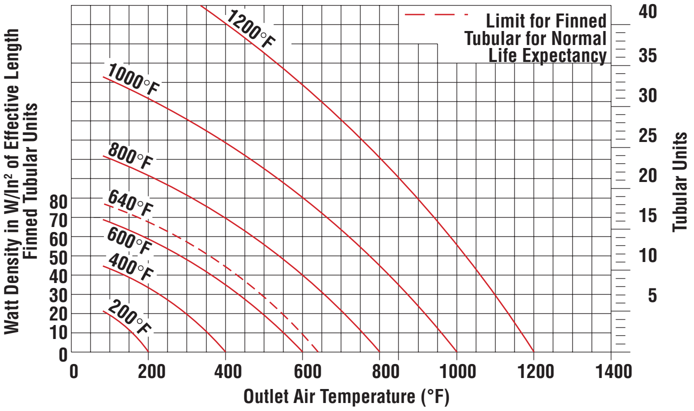
Graph G-153-1 — Fintube® & Tubular Heaters Sheath Temperatures with 9 FPS Distributed Air Velocity



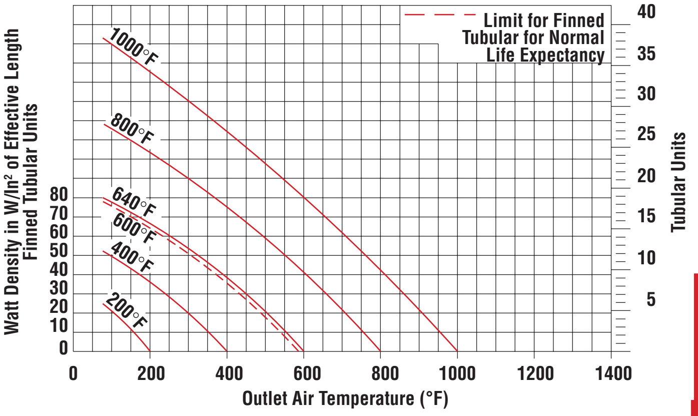
Graph G-154-1 — Fintube® & Tubular Heaters Sheath Temperatures with 16 FPS Distributed Air Velocity



Graph G-155-1 — Fintube® & Tubular Heaters Sheath Temperatures with 25 FPS Distributed Air Velocity



Graph G-156-1 — Fintube® & Tubular Heaters Sheath Temperatures with 36 FPS Distributed Air Velocity



Technical Information

Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating — Cryogenics

Industrial gases are usually stored in a liquid state with heat being added to vaporize and boil off the gas as usage requires. General heat equations apply except that pipes, tubes and vessels containing the cryogenic fluid or gas frequently represent a heat source rather than a heat loss. If the size and materials of the tanks or vessels are known, then heat calculations for the temperature rise can be performed as in standard vessel heating or boiler problems. The following example is typical of a cryogenic heating application.

Problem — Vaporize and preheat 30,000 SCFH of liquid Nitrogen (N_2) from -345°F to 70°F at atmospheric conditions. The properties of N_2 from Cryogenic Gas Tables are: Boiling point, -320°F Specific heat Btu/lb/°F = 0.474 (liq.), 0.248 (gas) Latent heat of vaporization = 85.7 Btu/lb Atm. density of N_2 at 32°F = 0.0784 lb/ft^3.

Solution — Amount of liquid N_2 to be vaporized 30,000 SCFH x 0.0784 lb/ft^3 = 2,352 lbs/hr

1. **Raise** liquid from -345°F to -320°F (boiling point) ΔT = 25°F.

$$\text{kW} = \frac{\text{Wt x } C_p \text{ x } \Delta T \text{ x SF}}{\text{3412 Btu/kW}}$$

Where:
Wt = Weight of material in lbs
C_p = Specific heat of the liquid N_2
ΔT = Temperature rise in °F
SF = Suggested safety factor of 20%

$$\text{kW} = \frac{\text{2,352 lbs x 0.474 x 25}}{\text{3412 Btu/kW}} \text{ x 1.2 = 9.8 kW}$$

2. **Vaporize** the liquid N_2

$$\text{kW} = \frac{\text{2,352 lbs x 85.7}}{\text{3412 Btu/kW}} \text{ x 1.2 = 70.9 kW}$$

3. **Raise** the temperature of the N_2 from boiling point -320°F to 70°F — ΔT = 390°F.

$$\text{kW} = \frac{\text{2,352 lbs x 0.248 x 390}}{\text{3412 Btu/kW}} \text{ x 1.2 = 80 kW}$$

Total kW/hr required = 9.8 + 70.9 + 80 = 169.7

Equipment Recommendations — Generally, cryogenic applications utilize both a vaporizer unit and a gas preheater. High watt density heaters immersed in the cryogenic fluid can be used for the vaporizer. Standard circulation heaters and watt densities are recommended for gas preheating. Protect the heater terminals from frost and moisture with element seals and liquid tight terminal covers.

Material Recommendations — Ordinary carbon steel is subject to brittle fracture at temperatures below -20°F and is generally not recommended. Stainless steel, high nickel bearing alloys or aluminum alloys may be used. Use Teflon® for gaskets asTeflon® remains pliable at low temperatures.

Air & Gas Heating — Batch Ovens

Most oven applications consist of heating work product inside an insulated enclosure. Heat loss calculations involve the determination of the heat requirements to heat the enclosure and work product using heated air circulated by natural or forced convection. Any make up or ventilation air must also be considered. The following example outlines the calculation of the heat required for a typical oven heating application.

Problem — An oven with inside dimensions of 2 ft H x 3 ft W x 4 ft D is maintained at 350°F. The oven has sheet steel walls with 2 inches of insulation and is ventilated with 400 cfh (ft^3/hr) of 70°F air which exhausts to the outside to remove fumes. The oven is charged with 250 lbs of coated steel parts on a steel tray weighing 40 lbs. The process requires the parts to be heated from 70°F to 350°F in 3/4 hour.

Weight of steel = 290 lbs
Specific heat of steel — 0.12 Btu/lb/°F
Weight of air = 0.080 lbs/ft^3 at 70°F
Specific heat of air = 0.24 Btu/lb/°F
Temperature rise = 280°F
Surface losses with 2 inch insulation = 18 W/ft^2/hr at 280°F temperature difference (Graph G-126S)
Surface area of oven = 52 ft^2
Time = 3/4 hr (0.75)
Airflow rate = 400 ft^3/hr

Solution —

1. **Calculate** kWh required to heat metal.

$$\text{kW} = \frac{\text{290 lbs x 0.12 Btu/lb/°F x 280°F}}{\text{3412 Btu/kW}} = \text{2.86 kW}$$

2. **Calculate** kWh required to heat ventilated air

$$\text{kW} = \frac{\text{400 cfh x 0.080 Lbs x 0.24 } C_p \text{ x 280 } \Delta T \text{ x 0.75 } t}{\text{3412 Btu/kW}} = \text{0.47kW}$$

Where:
cfh = Air flow rate (400)
Lbs/ft^3 = Density of air (0.080)
C_p = Specific heat of air (0.24)
ΔT = Temperature rise (280)
= Time in hours (0.75)

3. **Calculate** surface losses. Since the oven is already at temperature, losses are at full value.

$$\text{kW} = \frac{\text{18 W/ft}^2\text{/hr x 52 ft}^2 \text{ area x 0.75 hr}}{\text{1,000 W/kW}} = \text{0.70 kW}$$

4. **Total** kW = 2.86 + 0.47 + 0.70 = 4.03 kW

5. **For Oven Applications**, add 30% to cover door losses and other contingencies. kWh required (including safety factor) is

$$\text{kWh} = \frac{\text{kW}}{t} = \frac{\text{4.03 kW}}{\text{0.75 hrs}} = \text{5.37 kW x 1.3 = 6.98 kW}$$

Equipment Recommendations — Several process air heaters, including strip heaters, finstrips, bare tubulars or type OV oven heaters, are suitable for oven heating applications.

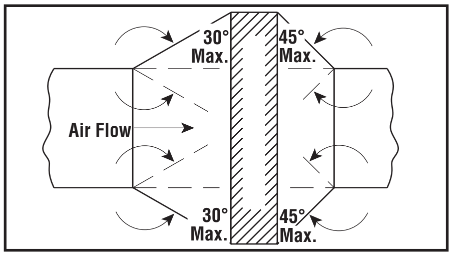
Pressure Drop for Process Air Heaters

The pressure drop through TDH and ADH process air heaters with bare tubular or finned tubular elements, CAB heaters with finstrip elements, and ADH and DH air heaters with finned tubular elements will vary considerably depending on product design and construction. Chromalox sales engineering can provide pressure drop calculations for virtually any duct heater (or circulation heater) application. Graphs G-112S3, G-189S1, G-227-2, and G-227ADH on the following page provide guidance for estimating the pressure drop for many Chromalox process air heaters[1]. Graph G-189S1 can be used for most finned tubular applications providing the elements are mounted in a three or six row configuration.

Transitions in Ducts — In some air distribution systems, the duct heater may be considerably larger or smaller than the associated ductwork. The duct heater can be adapted to different size ductwork by installing a sheet metal transition. The transition must be designed so that the slope on the upstream side of the equipment is limited to 30° (see below). On the leaving side, the slope should not be more than 45°.

Note 1 — Contact the factory for pressure drop calculations for duct heaters mounted lengthwise or in series and for GCH gas circulation heaters. These applications require special calculations for proper application and air handler sizing.

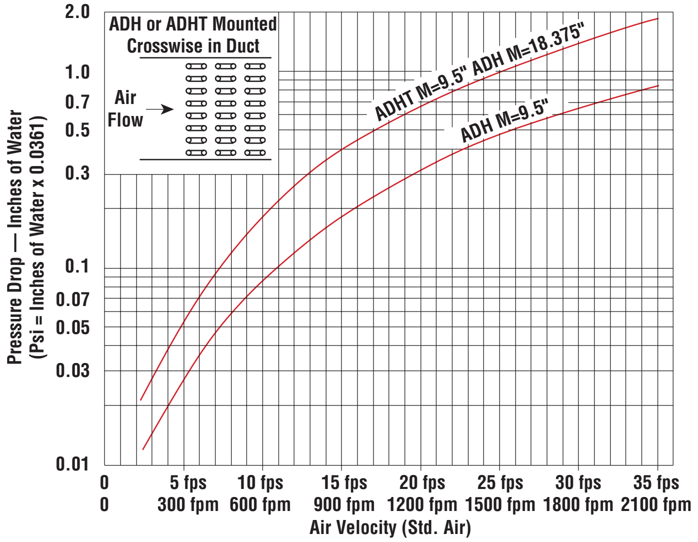
Recommended Dimensions for Duct Transitions



Technical Information

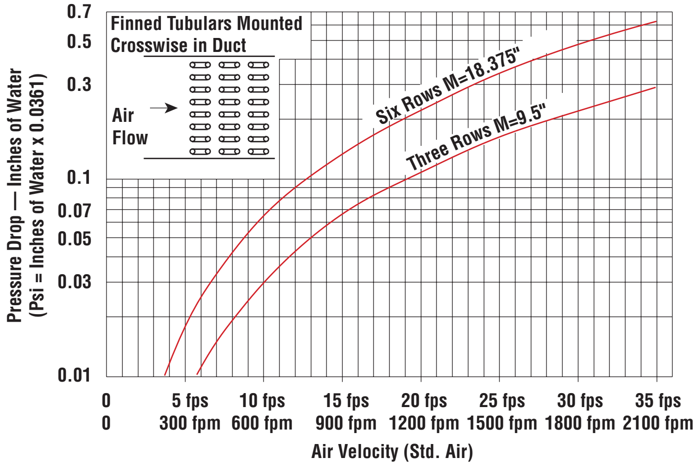
Determining Pressure Drop - Air and Gas Heating

Graph G-227ADH — Pressure Drop Vs. Velocity ADH and ADHT Tubular Element Air Heaters



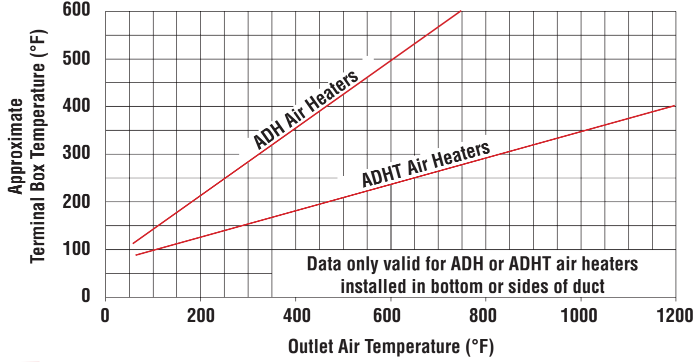
Note — Contact factory for pressure drop calculations for ADH/ADHT air heaters mounted lengthwise in duct and ADHT heaters where M is greater than 9.5"

Graph G-189S1 — Pressure Drop Vs. Velocity Fintube® Elements and Air Heaters

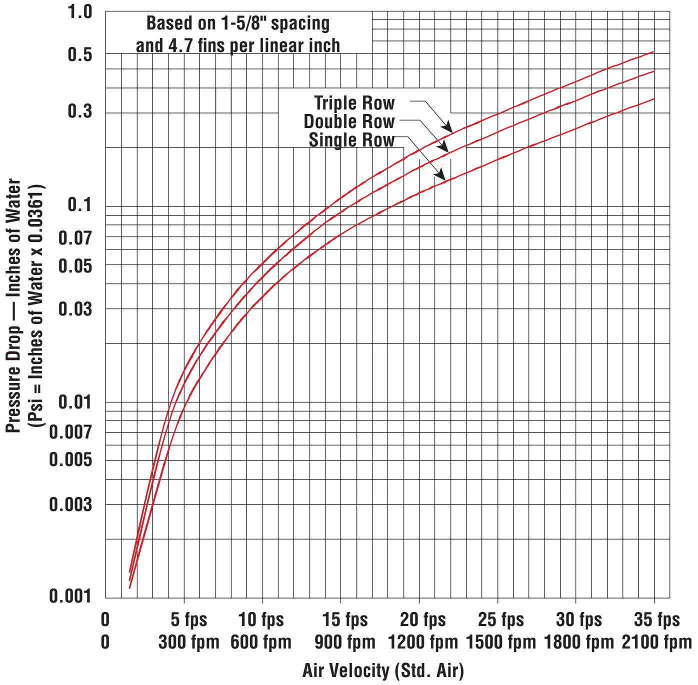


Note — Contact factory for pressure drop calculations for finned tubular element air heaters mounted lengthwise in duct.

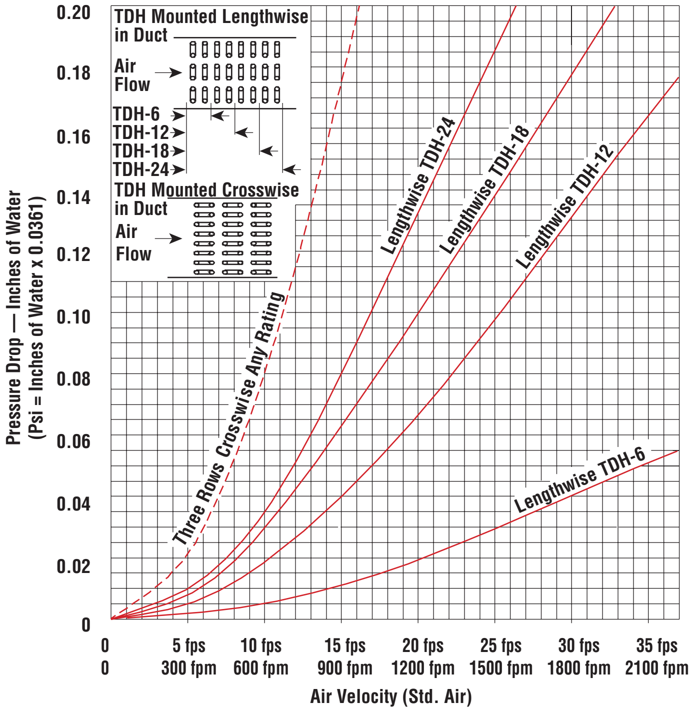
Graph ADHTB — ADH/ADHT Terminal Box Temperatures Field Wiring Selection Guide



Graph G-112S3 — Pressure Drop Vs. Velocity Finstrip® and CAB Air Heaters



Graph G-227-2 — Pressure Drop Vs. Velocity TDH Tubular Element Air Heaters



Technical Information

Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating with Circulation Heaters

To calculate the heat energy requirements for heating compressed air or gases, the first step is to determine the flow rate in pounds per hour. If the density of the air or gas under the actual pressure is known, the kW requirements can be calculated directly. The following example illustrates this procedure.

Example — Heat 20 ACFM of air at 30 psig from 60°F to 210°F. From the Properties of Air Chart, the density of air at 60°F and 30 psig is 0.232 lb/ft³ with a specific heat of 0.24 Btu/lb/°F. The kW required can be calculated from the formula:

$$\text{kW} = \frac{\text{ACFM x lbs/ft}^3\text{ x 60 min x } C_p \text{ x } \Delta T}{3412 \text{ Btu/kW}} \text{ x SF}$$

Where:

ACFM = Actual flow in ft³/min at inlet temperature and gauge pressure (psig)

Lbs/ft³ = Actual density at inlet temperature and gauge pressure (psig)

C_p = Specific heat of air or gas at inlet temperature and gauge pressure (psig)

ΔT = Temperature rise in °F

SF = Suggested Safety Factor

$$\text{kW} = \frac{20 \text{ x } 0.232 \text{ x } 60 \text{ x } 0.24 \text{ x } (210 - 60°\text{F})}{3412} \text{ x } 1.2$$

$$\text{kW} = \frac{278.4 \text{ lbs/hr x } 24 \text{ x } 150}{3412} \text{ x } 1.2 = 3.52 \text{ kW}$$

When the density and specific heat of a gas at a specific temperature and pressure are unknown, the actual flow rate can be converted to a known pressure and temperature using the physical laws of gases.

Example — Heat 45 ACFM of Nitrogen (N_2) at 35 psig from 50°F to 300°F. From the Physical and Thermodynamic Properties of Common Gases Chart, the density of Nitrogen at 70°F is 0.073 lb/ft³ with a specific heat of 0.2438 Btu/lb/°F. Convert 45 ACFM at 35 psig and 50°F to SCFM of Nitrogen at 70°F using the following formula:

$$\text{SCFM} = \text{ACFM x } \frac{\text{Actual psia}}{14.7 \text{ psia}} \text{ x } \frac{\text{Standard T}}{\text{Actual T}}$$

SCFM = Std. ft³/min at 14.7 psia and 70°F

ACFM = Actual flow in ft³/min at inlet temperature and gauge pressure (psig)

Actual psia = gauge pressure in lb/in² + 14.7 psia

14.7 psia = absolute pressure in lb/in²

T = °Rankine (°F + 460)

$$\text{SCFM} = 45 \text{ x } \frac{(35 + 14.7)}{14.7 \text{ psia}} \text{ x } \frac{(70 + 460)}{(50 + 460)}$$

SFCM = 158.1 ft³/min

Using the calculated SCFM in place of ACFM in equation A, the kW required is:

$$\text{kW} = \frac{158.1 \text{ x } 0.073 \text{ x } 60 \text{ x } 0.2438 \text{ x } (300 - 50)}{3412} \text{ x } 1.2$$

kW = 14.8 kW

Determining Maximum Sheath & Chamber Temperatures

When heating air or gases in insulated pipe chambers or circulation heaters, the pipe wall temperature will normally exceed the outlet gas temperature. Excessively high wall and/or sheath temperatures can create an unsafe or dangerous condition. Maximum sheath and chamber temperatures can be estimated using the mass velocity of the gas and Graph G-237. In the above air heating example, assume a 4.5 kW Series 3 heater rated 23 W/in² has been selected. From Chart 236, the free cross sectional area of a Series 3 (3 inch) heater is 0.044 ft². Calculate mass velocity from the following equation:

$$\underset{(\text{lbs/ft}^2\text{/sec})}{\text{Mass Velocity}} = \frac{\text{Flow lbs/hr}}{\text{Free area ft}^2} \div 3{,}600 \frac{\text{sec}}{\text{hr}}$$

$$\text{Mass Velocity} = \left(\frac{278 \text{ lbs/hr}}{0.044 \text{ ft}^2}\right) \div 3{,}600 \frac{\text{sec}}{\text{hr}}$$

Chart 236 — Circulation Heaters Free Internal Cross Sectional Area

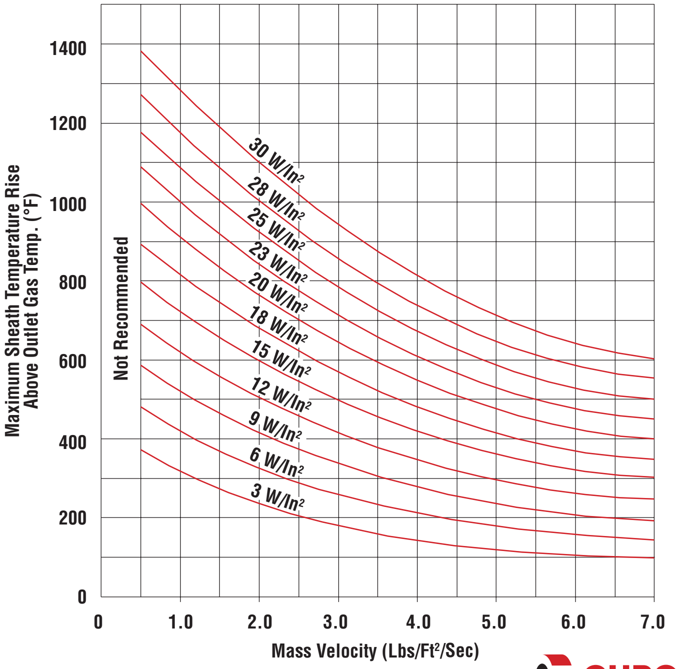
Pipe Body Nom. IPS (Std.)	Total Area (Ft²)	Free Area (Ft²)	No. 0.475" Elements
2	0.023	0.018	2
3	0.051	0.044	3
5	0.139	0.124	6
8	0.355	0.303	18
10	0.566	0.481	27
12	0.785	0.696	36
14	0.957	0.847	45
16	1.268	1.091	72
18	1.622	1.357	108

Mass Velocity = 1.75 lbs/ft²/sec

On Graph G-237, locate the mass velocity (1.75) on the horizontal axis. From that point, locate a 23 W/in² curve. Read across to the vertical axis (sheath temperature rise above outlet temperature) to 880°F. Adding 880°F + 210°F (outlet temp.) = 1090°F sheath temperature. Averaging the sheath and outlet temperatures (1090°F + 210°F ÷ 2), yields a maximum chamber temperature of 650°F.

Since the maximum chamber wall temperature is less than 750°F, a stock GCH heater with a carbon steel vessel and INCOLOY® elements rated 23 W/in² can be used.

Graph G-237 — Sheath Temperature Vs. Mass Velocity



Technical Information

Determining Heat Energy Requirements - Steam Heating

Steam Heating with Heat Exchangers — Shell and tube heat exchangers are frequently used to heat liquids where steam is available from central boilers or waste heat from processes. Electric steam boilers can be used as a supplemental or alternate steam source.

Example — A chemical company uses a shell and tube heat exchanger to heat 10 gpm of water from 140°F to 185°F for a continuous process. The exchanger is supplied with 50 psig steam from a large central boiler. The company wishes to shut down the large boiler in the summer months. What size boiler is needed to replace the central steam supply during shut down? Condensate is returned to the boiler mixed with 50°F feed water.

The heat energy required can be calculated from the following formula:

$$Q = \frac{(500\ \text{lb/hr})\ (C_p)\ (\text{SG})\ (\text{F})\ (\Delta T)\ (\text{C})}{\text{H}} \times 1.2\ \text{SF}$$

Where:
Q = Heat required in kW/hr
500 = Conversion factor — gpm to lbs/hr (1 gpm x 8.345 lbs/gal x 60 min = 500 lbs/hr)
C_p = Specific heat (Btu/lb/°F) — 1 for water
SG = Specific gravity of liquid — 1 for water
F = Flow of liquid — gal/min
ΔT = Temperature change of liquid °F (180°F - 140°F = 45°F)
C = Conversion factor — kW/lb of steam @ 50 psig (from kW/lb Conversion Table)
H = Latent heat of steam at operating pressure — Btu/lb (From Saturated Steam Table)
SF = Safety factor of 20%

$$Q = \frac{(500\ \text{lb/hr})\ (1)\ (1)\ (10)\ (45°\text{F})\ (0.3401\ \text{kW/lb})}{(912\ \text{Btu/lb})}$$

Q = 83.9 kW/hr x 1.2 SF - 100.7 kW/hr

A 20% safety factor is recommended to allow for unknown heat losses and the possible loss of heated condensate water due to flashing.

Steam Humidification in General Applications — The injection of steam into a moist air stream to increase humidity is a common air conditioning application. Calculations of steam humidification requirements can be separated into variable and constant air temperature applications. Equipment is usually sized based on boiler output in lbs/hr at 0-5 psig with 50°F feed water.

Variable Air Temperatures — The pounds of steam per hour required for variable temperature applications can be calculated from the formula:

$$F_H = \frac{(\Delta V)(F_M \times 60\ \text{min})}{100\ \text{CFM}}$$

Where:
F_H = Steam flow in lbs/hr
ΔV = Increase in moisture content lbs/ft^3 based on water vapor content of air at initial condition and at final condition
F_M - Air flow in CFM

Example — A greenhouse needs to increase the humidity of 850 CFM of incoming outside air at 40°F and 50% humidity; to 80°F and 75% humidity. Referring to the chart, “Water Content of Air” in the Reference Data Section, 40°F air at 50% humidity contains 0.021 lbs of water vapor per 100 ft^3. Air at 80°F and 75% humidity contains 0.119 lbs of water vapor per 100 ft^3. The pounds of water vapor to be added (ΔV) are 0.119 lbs - 0.021 lbs or 0.098 lbs per 100 cubic feet of air.

$$F_H = \frac{(0.098\ \text{lbs}/100\ \text{ft}^3)(850\ \text{CFM} \times 60\ \text{min})}{100\ \text{CFM}}$$

F_H - 49.98 lbs/hr

A 20% safety factor is recommended

F_H - 49.98 lbs/hr x 1.2 SF = 59.98 lbs/hr

Constant Air Temperature — Steam requirements for humidity in a typical constant air temperature application can be determined from the Booster Humidification Table.

Example — A laboratory room is supplied with 750 CFM of air at 75°F and 35% relative humidity. The company wants to boost the humidity in a laboratory from 35% to 60% while maintaining a temperature of 75°F. What size steam boiler is needed?

From the table, read the initial condition line at 75°F - 35% rh to the intersect of 60% rh = 2.03 lbs/hr/100 CFM

750 CFM ÷ 100 CFM x 2.03 lbs/hr = 15.225 lbs/hr

15.225 lbs/hr x 20% safety factor = 18.27 lbs/hr

Steam Super Heating — The primary objective in most steam superheating applications is to improve steam quality and eliminate “carryover”. In steam heating applications, the most efficient heat transfer occurs when high quality (100%) steam at saturation temperature is condensed in the heat exchanger or process. The majority of the thermal energy in the steam (latent heat of vaporization) is transferred when the steam condenses to water.

Unfortunately, the steam discharge from most steam boilers contains water molecules or mist that has not evaporated. This is called “wet steam” and is rated by quality factors ranging from 85% to 95%. Wet steam has a lower thermal transfer efficiency and is undesirable in many commercial applications. The excessive “carryover” of liquid water and mist in wet steam can create major performance problems in sterilizers and autoclaves.

To improve steam quality, wet steam can be superheated to create 100% quality or “dry steam” using a circulation heater. For example, steam at 90 psig has a saturation temperature of 331°F. Raising the temperature of 90 psig steam to 340°F or 350°F will produce 100% quality steam. An increase of 10° to 20° is usually more than adequate for most applications. Higher temperatures may be necessary if there are excessive pipe and equipment losses.

Unless there are other operating conditions that require high steam temperatures, increasing the temperature more than 20° - 30° above saturation temperature is not recommended. Increasing the steam temperature without increasing the gauge pressure does not significantly increase the heat content or heat transfer characteristics of the steam. The heat energy required to superheat steam can be plotted from the Steam Superheat Nomograph shown in this section.

Booster Humidification

Initial Condition		Relative Humidity Desired						
°F	R.H.	40%	45%	50%	55%	60%	65%	70%
70	35%	0.345	0.690	1.03	1.38	1.72	2.07	2.42
70	40%	—	0.345	0.69	1.03	1.38	1.72	2.07
72	35%	0.368	0.728	1.10	1.46	1.83	2.20	2.57
72	40%	—	0.368	0.73	1.10	1.46	1.83	2.20
75	35%	0.405	0.810	1.22	1.62	2.03	2.43	2.84
75	40%	—	0.405	0.81	1.22	1.62	2.03	2.43

Note — Lbs-vapor/hr/100 CFM required to secure desired relative humidity with no change in air temperature.

Technical Information

Steam Superheating

Calculating kW Requirements for Superheating Steam

The nomograph shown below can be used to determine the kilowatts required to superheat saturated steam to higher temperatures.

Example — Heat 560 lbs/hr of 90% quality steam at 110 psig to 440°F at the same pressure. On line P, plot the gauge pressure (psig). Read the saturated steam temperature at operating pressure. Subtract from desired final temperature to determine degrees of superheat (ΔT).

(ΔT) = 440°F - 344°F = 96°F

Draw a straight line from P through line Q and read the intersect at line $W(W_1)$. Next, draw a straight line from same point on line P through S (°F of superheat) and read the intersect on line $W(W_1)$. Determine kW using W_1 and W_2 in the following formula.

$$\text{kW/hr} = \frac{(\text{lbs/hr})\ (W_2 - W_1)\ \text{x 1.2 SF}}{\text{1000 W/kW}}$$

$$\text{kW/hr} = \frac{(\text{560 lbs/hr})\ (82-39)\ \text{x 1.2 SF}}{\text{1000 W/kW}}$$

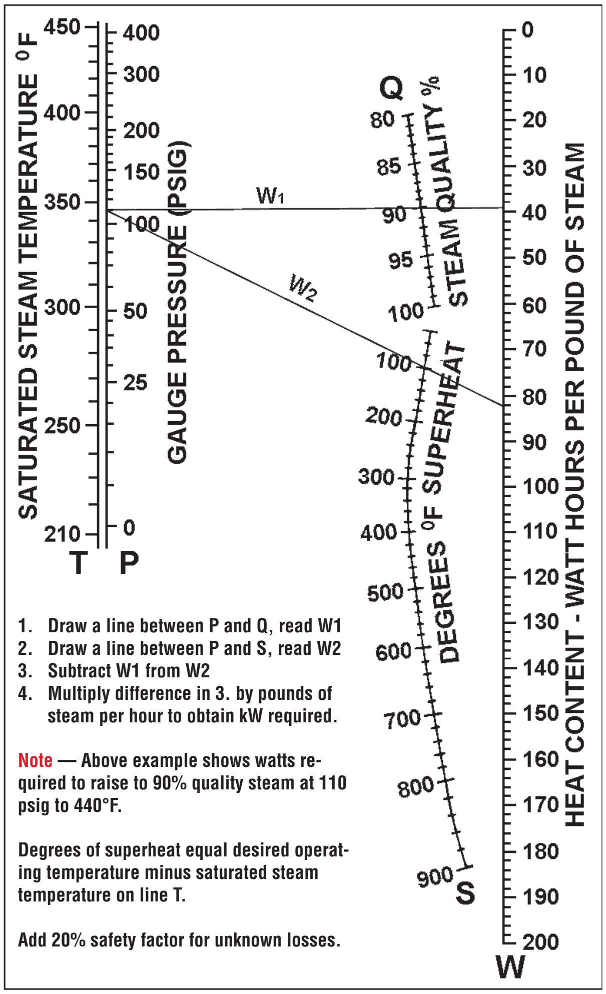
kW/hr = 28.896

Determining Sheath and Chamber Temperatures for Superheated Steam — Since superheated steam is essentially a gas, the last step in the above procedure is to determine maximum sheath and chamber temperatures of the circulation heater using Chart 236 and Graph G-237 for air and gas heating. In the above example, assume Series 6 heater with a standard 23 W/in^2 rating. From the charts:

Sheath Temperature = 1440°F
Chamber Temperature = 940°F

Select a Series 6 heater capable of the above operating conditions from the product pages in the Circulation Heater Section.

Steam Superheat Nomograph



1. Draw a line between P and Q, read W1
2. Draw a line between P and S, read W2
3. Subtract W1 from W2
4. Multiply difference in 3. by pounds of steam per hour to obtain kW required.

Note — Above example shows watts required to raise to 90% quality steam at 110 psig to 440°F.

Degrees of superheat equal desired operating temperature minus saturated steam temperature on line T.

Add 20% safety factor for unknown losses.

Technical Information

Properties of Steam

Saturated Steam

The thermodynamic properties of saturated steam are shown in the table to the right. Saturated steam is pure steam in direct contact with the liquid water from which it was generated and at the same temperature and pressure as the water. For example, saturated steam at 50 psig has a temperature of 298°F.

Steam pressure is commonly expressed as **psia** or **psig**. Psia is pounds per square inch absolute with reference to a perfect vacuum. Psig is pounds per square inch gauge with reference to atmospheric pressure of 14.7 psi psia = psig + 14.7 psi (1 atmosphere).

The heat content of liquid is the heat energy in Btu/lb required to heat the liquid to the condition indicated starting with water at 32°F.

Latent heat is the heat energy in Btu/lb absorbed when a pound of boiling water is converted to a pound of steam at the same temperature. The same amount of heat is released when the steam condenses back to water at the same temperature. Latent heat varies with temperature.

Saturated Steam — Thermodynamic Properties (nearest even digit)

Gauge Press. (psig)	(°F)	Btu/lb			Sat. Vapor (ft^3/lb)	Gauge Press. (psig)	Temp. (°F)	Btu/lb			Sat. Vapor (ft^3/lb)
		Liquid Heat	Latent Heat	Steam Total				Liquid Heat	Latent Heat	Steam Total	
0	212	180	970	1150	27.0	70	316	286	898	1184	5.2
1	216	183	968	1151	25.0	75	320	290	895	1185	4.9
2	219	187	965	1152	24.0	80	324	294	892	1186	4.7
3	222	190	964	1154	22.5	85	328	298	889	1187	4.4
4	224	193	962	1155	21.0	90	331	302	886	1188	4.2
5	227	195	961	1156	20.0	95	335	306	883	1189	4.0
6	230	198	959	1157	19.5	100	338	309	881	1190	3.9
7	232	201	957	1158	18.5	110	344	316	876	1192	3.6
8	235	203	956	1159	18.0	120	350	322	871	1193	3.3
9	237	206	954	1160	17.0	125	353	325	868	1193	3.2
10	240	208	952	1160	16.5	130	356	328	866	1194	3.1
15	250	218	945	1163	14.0	140	361	334	861	1195	2.9
20	259	227	940	1167	12.0	150	366	339	857	1196	2.7
25	267	236	934	1170	10.5	160	371	344	853	1197	2.6
30	274	243	929	1172	9.5	170	375	348	849	1197	2.5
35	281	250	924	1174	8.5	180	380	353	845	1198	2.3
40	287	256	920	1176	8.0	190	384	358	841	1199	2.2
45	292	262	915	1177	7.0	200	388	362	837	1199	2.1
50	298	267	912	1179	6.7	220	395	370	830	1200	2.0
55	303	272	908	1180	6.2	240	403	378	823	1201	1.8
60	307	277	905	1182	5.8	250	406	381	820	1201	1.75
65	312	282	901	1183	5.5	300	422	399	805	1204	1.48

Boiler Feed Water Temperature

The temperature of boiler feed water directly affects the steam output of a boiler. The following table can be used to determine the kilowatt rating of a boiler when the steam load, gauge pressure and boiler feed water temperature are known.

Example — A process requires 450 lbs of steam per hour at 75 psig. The available feed water temperature is 50°F. From the chart, read the kW/lb required for 50°F water and a gauge pressure of 75 psig. Multiply the factor by the pounds of steam: 0.3417 x 450 lbs = 153.8 kW.

Boiler Feed Water Temperature Vs. kW Required per Pound of Steam

Feed Water (°F)	Steam Gauge Pressure (psig)										
	0	2	10	15	25	40	50	75	100	125	150
40	.3347	.3355	.3375	.3388	.3406	.3422	.3431	.3447	.3458	.3464	.3470
50	.3318	.3326	.3345	.3359	.3376	.3392	.3401	.3417	.3429	.3435	.3441
60	.3288	.3296	.3316	.3329	.3347	.3363	.3372	.3388	.3400	.3407	.3411
70	.3259	.3267	.3287	.3300	.3318	.3334	.3343	.3359	.3370	.3376	.3382
80	.3229	.3238	.3278	.3271	.3288	.3305	.3313	.3329	.3341	.3347	.3353
90	.3200	.3208	.3238	.3242	.3259	.3275	.3284	.3300	.3312	.3318	.3324
100	.3171	.3179	.3199	.3212	.3229	.3246	.3255	.3271	.3283	.3288	.3294
110	.3142	.3150	.317	.3183	.3200	.3217	.3225	.3242	.3253	.3259	.3265
120	.3112	.3210	.314	.3154	.3171	.3187	.3196	.3212	.3224	.3230	.3236
130	.3083	.3091	.3111	.3124	.3142	.3160	.3167	.3183	.3195	.3200	.3206
140	.3054	.3062	.3082	.3095	.3113	.3129	.3137	.3154	.3165	.3171	.3177
150	.3025	.3032	.3052	.3066	.3083	.3099	.3108	.3124	.3136	.3142	.3148
160	.2995	.3003	.3029	.3036	.3054	.3070	.3079	.3095	.3107	.3113	.3118
170	.2966	.2974	.2994	.3001	.3025	.3041	.3050	.3066	.3077	.3083	.3089
180	.2937	.2945	.2964	.2978	.2995	.3011	.3020	.3036	.3048	.3054	.3060
190	.2907	.2915	.2935	.2948	.2966	.2982	.2981	.3007	.3019	.3025	.3030
200	.2878	.2886	.2906	.2919	.2937	.2953	.2962	.2978	.2989	.2995	.3001

Technical Information

Heating Solids - Platens, Dies & Molds

The calculation of heating requirements for heating solid materials (such as platens, dies and molds) is similar to other applications. The following is a typical application problem:

Example — A plastic forming process uses 20 lbs of plastic (Cp = 0.45 Btu/lb/°F) per hour. The plastic is pliable at 300°F and is formed by two steel platens, each 24 in. long x 12 in. wide x 3 in. thick and weighing 245 lbs. The platens must be preheated to 300°F in the closed position within 30 minutes. The top and bottom of the platens (press side) are insulated with 1/2" of rigid insulation.

Initial Heat Up — To heat the steel platens (Cp = 0.12 Btu/lb/°F)

$$kW = \frac{\text{Lbs} \times Cp \times \Delta T}{3412\ \text{Btu/kW} \times t}$$

$$kW = \frac{245\ \text{lbs} \times 2 \times 0.12\ \text{Btu/lb/°F} \times (300 - 70°\text{F})}{3{,}412\ \text{Btu/kW} \times 0.5\ \text{hrs.}}$$

kW = 7.93

Losses from exposed edges during heat-up: (See Graph G-125S, Curve "A", for oxidized steel.) Edge area = 2 (2 ft) + 2 (1 ft) x 0.5 ft = 3 ft^2

$$kW = \frac{3\ \text{ft}^2 \times 200\ \text{W/ft}^2\text{/hr}}{1000\ \text{W/kW}} = 0.6\ \text{kW/hr}$$

Losses by conduction from top and bottom insulated surfaces of the platen —

$$kW = \frac{\text{Area ft}^2 \times k \times \Delta T}{3412\ \text{Btu/kW} \times d}$$

Where:
k = 0.45 Btu/hr/in/Ft^2/°F thermal conductivity of rigid insulation (Properties of Non-metallic Solids) d = thickness of insulation (0.5 inch)

$$kW = \frac{2(2\ \text{ft}^2) \times 0.45 \times (300 - 70°\text{F})}{3412\ \text{Btu/kW} \times 0.5\ \text{in.}} = 0.24\ \text{kW/hr}$$

Average losses 0.6 kW + 0.24 kW ÷ 2 = 0.42 kW/hr

kW for start up = 7.93 + 0.42 x 1.2 SF = 10.0 kW

Operating Requirements — (Assume losses from opening and closing the platens are negligible.) To heat plastic:

$$kW = \frac{20\ \text{lbs} \times 0.45\ \text{Btu/lb/°F} \times (300 - 70°\text{F})}{3412\ \text{Btu/kW}} = 0.61\ \text{kW}$$

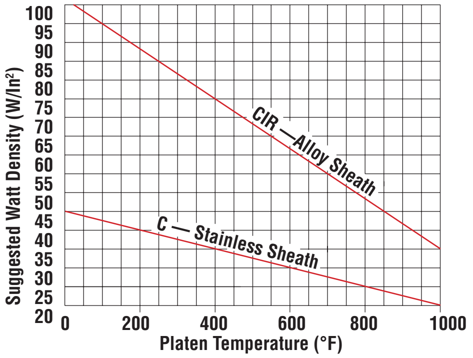
Losses = 0.6 kW + 0.24 kW = 0.84 kW
Total kW = 0.61 kW + 0.84 kW = 1.45 kW
Required kW = 1.45 kW x 1.2 SF = 1.74 kW

Since the heat-up requirement is greater than that for operation, install 10 kW.

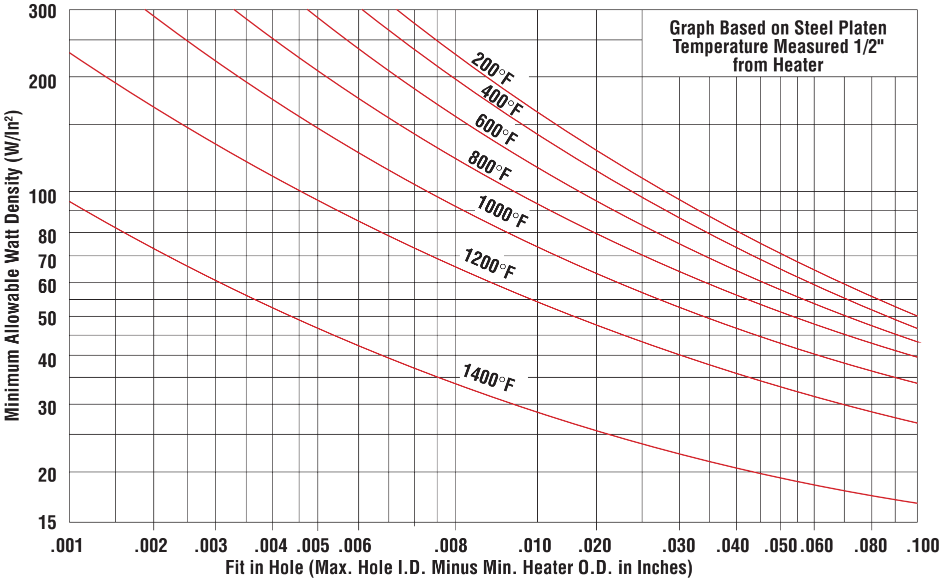
Heater Selection — While most platen and die heating applications are accomplished with cartridge heaters, strip or tubular heaters may also be used by inserting them into grooved slots in the metal. (See clamp-on heater applications.) When selecting cartridge heaters, it is essential that the following factors be considered to ensure reasonable heater life and sufficient heat.

1. **Select Watt Density** — The maximum permissible sheath watt densities for INCOLOY® sheath (CIR) cartridge heaters for a given metal temperature are shown on Graph G-235A. These curves plot the recommended watt densities for various hole clearances. Graph G-201 is useful for determining watt density for optimum life when selecting type CIR heaters.
2. **Determine Proper Fit** — When cartridge heaters are installed in a machined or drilled hole, the hole should be sized to the nominal diameter of the heater. For best fit, holes should be drilled slightly undersized and reamed to the nominal heater diameter. Actual diameters of standard cartridge heaters are 0.003 to 0.005" smaller than nominal. This allows for easy installation when cold. Sheath expansion upon heating provides an interference fit and maximum heat transfer.
3. **Protect Cartridge Heaters from External Contamination** — Contamination can occur when moisture, oil, etc. enters the sheath through the lead wires or terminal end. (The end opposite the lead wires is protected by a seal welded end disc.) Contamination frequently causes short life and dielectric failure. Special moisture resistant terminal constructions are available and hermetic seals can be supplied when severe contamination problems are present.
4. **Provide Mechanical Protection for the Lead Wires** — Most high temperature lead wire electrical insulations have little resistance to mechanical abrasion. Special constructions using sleeving or conduit for mechanical protection are available.

Graph G-201 — Suggested Watt Density Limits for Optimum Life



Graph G-235A — Maximum Watt Density Vs. Platen Temperature for Various Fits Using Type CIR Cartridge Heaters



Technical Information

Heating Exchangers - Heating & Cooling

General Information

In addition to direct heating with electric heating elements, Chromalox can provide heat exchangers for use with circulating hot or cold water systems or with steam as the heating media. The heat exchangers are designed to heat water solutions in plating baths and other corrosive applications and are available in Stainless Steel, Titanium or Teflon®. Check the Corrosion Guide in this section for proper sheath material selection. The procedures and calculations for using these heat exchangers are shown below: The procedures are based on closed and insulated tanks (see note below).

Using Steam Heating Media

The heating capacity requirements for using steam as the heating media can be determined from the following formula:

$$\frac{V \times \Delta T \times S_{PF} = \text{ft}^2/\text{hr}}{1000}$$

Where:
V = Gallons of liquid to be heated
ΔT = Desired temperature rise or change in temperature °F
S_{PF} = Steam pressure factor from Table 1
Ft^2 = Square feet of heat exchanger required to provide heat up in one hour

Calculation Procedure

1. **Determine** gallons in tank to be heated.
2. **Subtract** the temperature of the solution to be heated from the desired temperature.
3. **Locate** the usable steam pressure in Table 1 and determine the Steam Pressure Factor.
4. **Apply** the Steam Pressure Factor to the above equation and solve for area in square feet.
5. **Select** the heat exchanger from the product pages that matches the requirements.

Table 1 — Steam Pressure Factor

Exchangers	Steam Pressure Available (psig)						
	5	10	15	20	25	30	Above 30
Metal	0.55	0.50	0.42	0.37	0.30	0.27	Note[1]
Teflon®	2.2	2.0	1.7	1.5	1.3	1.1	Note[1]

1. Contact your Local Chromalox Sales office for recommendations for steam pressures over 30 psig.

Using Hot Water Heating Media

The heating capacity requirements for using hot water as the heating media can be determined from the following formula:

$$\frac{V \times \Delta T \times 8.33 = \text{ft}^2/\text{hr}}{U \times (T_1 - T_2)}$$

Where:
V = Gallons of liquid to be heated
ΔT = Desired temperature rise or change in temperature °F
U = Factor for coil type
U factor for Metal Coils — 90
U factor for Teflon® Coils — 40
T_1 = Temperature of incoming hot water media
T_2 = Final temperature of solution to be heated
Ft^2 = Square feet of heat exchanger required to provide heat up in one hour

Calculation Procedure

1. **Determine** gallons in tank to be heated.
2. **Subtract** the initial temperature of the solution to be heated from the desired temperature.
3. **Determine** the proper U factor for the particular type heat exchanger selected.
4. **Determine** temperature of incoming hot water supply.
5. **Apply** the above equation and solve for area in square feet.
6. **Select** the heat exchanger from the product pages that matches the requirements.

The above equation gives the square feet of heat exchanger needed to complete the heat up operation in one hour. If more time is available, the coil surface area (ft^2) may be reduced by dividing the square feet from the above equation by the heat up time available. The correction factor can be used for time periods up to 4 hours maximum.

Note — When heating open tanks, the heat loss from the water surface must be added to the heating requirements (see Graph G-114S).

Using Cold Water Cooling Media

In electroplating operations, considerable heat is added to the plating solution by the plating current. Frequently it is desirable to cool the plating bath without diluting or upsetting the chemical balance by introducing cold water directly into the solution. Heat exchangers provide the ideal solution to this problem. The cooling capacity requirements for using cold water as the cooling media for a plating bath can be determined from the following formula:

$$\frac{V_R \times A_R \times 3.412 \text{ Btu/W} = \text{ft}^2/\text{hr}}{U \times (T_1 - T_2)}$$

Where:
V_R = Voltage of rectifier
A_R = Amperage or current of rectifier
U = Factor for coil type
U factor for Metal Coils — 90
U factor for Teflon® Coils — 40
T_1 = Final temperature of solution to be cooled
T_2 = Temperature of incoming cold water media
Ft^2 = Square feet of heat exchanger required to provide cool down in one hour

Calculation Procedure

1. **Determine** the watts of energy from the rectifier by multiplying the volts times amps. Convert watts to Btu by dividing by 3,412.
2. **Determine** the proper U factor for the particular type heat exchanger selected.
3. **Determine** temperature of incoming cold water supply.
4. **Subtract** the temperature of the cooling water from the desired temperature of the solution to be cooled. **CAUTION** — If the difference in temperature is less than 15°F, contact your Local Chromalox Sales office for assistance in determining proper coil size.
5. **Apply** the above equation and solve for area in square feet.
6. **Select** the heat exchanger from the product pages that matches the requirements.

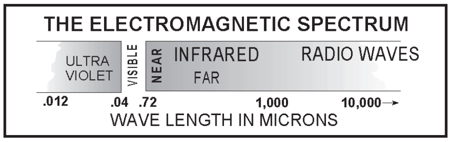
Technical Information

Radiant Infrared Heating - Theory & Principles

Infrared Theory

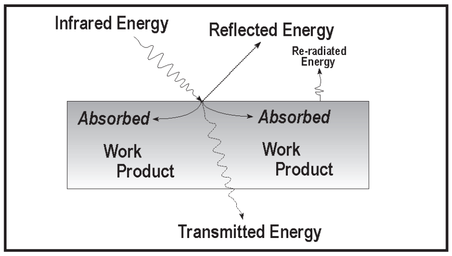
Infrared energy is radiant energy which passes through space in the form of electromagnetic waves (Figure 1). Like light, it can be reflected and focused. Infrared energy does not depend on air for transmission and is converted to heat upon absorption by the work piece. In fact, air and gases absorb very little infrared. As a result, infrared energy provides for efficient heat transfer without contact between the heat source and the work piece.

Figure 1



Infrared heating is frequently missapplied and capacity requirements underestimated due to a lack of understanding of the basic principles of radiant heat transfer. When infrared energy from a source falls upon an object or work piece, not all the energy is absorbed. Some of the infrared energy may be reflected or transmitted. Energy that is reflected or transmitted does not directly heat the work piece and may be lost completely from the process (Figure 2).

Figure 2

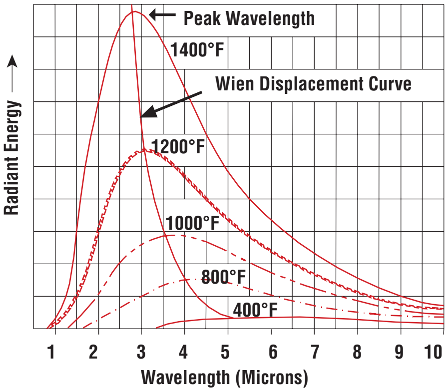


Another important factor to consider in evaluating infrared applications is that the amount of energy that is absorbed, reflected or transmitted varies with the wave length of the infrared energy and with different materials and surfaces. These and other important variables have a significant impact on heat energy requirements and performance.

Infrared Emitters & Source Temperatures — The amount of radiant energy emitted from a heat source is proportional to the surface temperature and the emissivity of the material. This is described by the Stefan-Boltzmann Law which states that radiant output of an ideal black body is proportional to the fourth power of its absolute temperature. The higher the temperature, the greater the output and more efficient the source.

Emissivity and an Ideal Infrared Source — The ability of a surface to emit radiation is defined by the term *emissivity.* The same term is used to define the ability of a surface to absorb radiation. An ideal infrared source would radiate or absorb 100% of all radiant energy. This ideal is referred to as a "perfect" black body with an *emissivity* of unity or 1.0. The spectral distribution of an ideal infrared emitter is below.

Spectral Distribution of a Blackbody at Various Temperatures



Note — As the temperature increases, the peak output of the source shifts to the left of the electromagnetic spectrum with a greater percentage of the output in the near infrared range. This is referred to as the Wien Displacement Curve and is an important factor in equipment selection.

Emissivity — In practice, most materials and surfaces are "gray bodies" having an emissivity or absorption factor of less than 1.0. For practical purposes, it can be assumed that a poor emitter is usually a poor absorber. For example, polished aluminum has an emissivity of 0.04 and is a very poor emitter. It is highly reflective and is difficult to heat with infrared energy. If the aluminum surface is painted with an enamel, emissivity increases to 0.85 - 0.91 and is easily heated with infrared energy. Table 1 lists the emissivity of some common materials and surfaces.

Absorption — Once the infrared energy is converted into heat at the surface, the heat travels into the work by conduction. Materials such as metals have high thermal conductivity and will quickly distribute the heat uniformly throughout. Conversely, plastics, wood and other materials have low thermal conductivity and may develop high surface temperatures long before internal temperatures increase appreciably. This can be an advantage when using infrared heating for drying paint, curing coatings or evaporating solvents on non-metal substrates.

Reflectivity — Materials with poor emissivity frequently make good reflectors. Polished gold with an emissivity of 0.018 is an excellent infrared reflector that does not oxidize easily. Polished aluminum with an emissivity of 0.04 is an excellent second choice. However, once the surface of any metal starts to oxidize or collect dirt, its emissivity increases and its effectiveness as an infrared reflector decreases.

Table 1 — Approximate Emissivities

Metals	Polished	Rough	Oxidized
Aluminum	0.04	0.055	0.11-0.19
Brass	0.03	0.06-0.2	0.60
Copper	0.018-0.02	—	0.57
Gold	0.018-0.035	—	—
Steel	0.12-0.40	0.75	0.80-0.95
Stainless	0.11	0.57	0.80-0.95
Lead	0.057-0.075	0.28	0.63
Nickel	0.45-0.087	—	0.37-0.48
Silver	0.02-0.035	—	—
Tin	0.04-0.065	—	—
Zinc	0.045-0.053	—	0.11
Galv. Iron	0.228	—	0.276
Miscellaneous Materials			
Asbestos			0.93-0.96
Brick			0.75-0.93
Carbon			0.927-0.967
Glass, Smooth			0.937
Oak, Planed			0.895
Paper			0.924-0.944
Plastics			0.86-0.95
Porcelain, Glazed			0.924
Quartz, Rough, Fused			0.932
Refractory Materials			0.65-0.91
Rubber			0.86-0.95
Water			0.95-0.963
Paints, Lacquers, Varnishes			
Black/White Lacquer			0.8-0.95
Enamel (any color)			0.85-0.91
Oil Paints (any color)			0.92-.096
Aluminum Paint			0.27-0.67

Transmission — Most materials, with the exception of glass and some plastics, are opaque to infrared and the energy is either absorbed or reflected. Transmission losses can usually be ignored. A few materials, such as glass, clear plastic films and open fabrics, may transmit significant portions of the incident radiation and should be carefully evaluated.

Controlling Infrared Energy Losses — Only the energy absorbed is usable in heating the work product. In an unenclosed application, losses from reflection and re-radiation can be excessive. Enclosing the work product in an oven or a tunnel with high reflective surfaces will cause the reflected and re-radiated energy to be reflected back to the work product, eventually converting most of the original infrared energy to useful heat on the work product.

Technical Information

Radiant Infrared Heating - Source Evaluations

Evaluating Infrared Sources

Commonly available infrared sources include heat lamps, quartz lamps, quartz tubes, metal sheath elements, ceramic elements and ceramic, glass or metal panels. Each of these sources has unique physical characteristics, operating temperature ranges and peak energy wavelengths. (See characteristics chart below.)

Source Temperature & Wave Length Distribution — All heat sources radiate infrared energy over a wide spectrum of wavelengths. As the temperature increases for any given source:

1. The total infrared energy output increases with more energy being radiated at all wavelengths.
2. A higher percentage of the infrared energy is concentrated in the peak wavelengths.
3. The energy output peak shifts toward the shorter (near infrared) wavelengths.

The peak energy wavelength can be determined using Wien's Displacement Law.

$$\text{Peak Energy (Microns)} = \frac{5269 \text{ microns/°R}}{\text{Source Temp. (°F)} + 460}$$

$$\text{Source } 1400\text{°F} = \frac{5269 \text{ microns/°R}}{1400\text{°F} + 460} = 2.83 \text{ microns}$$

$$\text{Source } 500\text{°F} = \frac{5269 \text{ microns/°R}}{500\text{°F} + 460} = 5.49 \text{ microns}$$

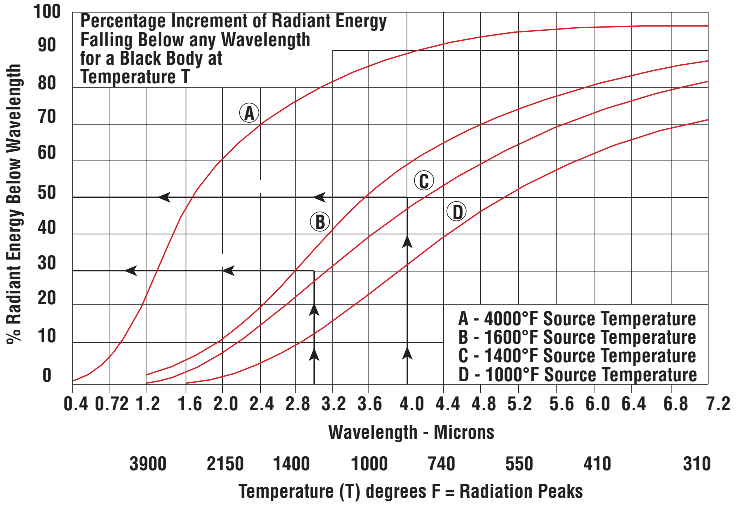
Absorption by Work Product Materials in Process Applications — While most materials absorb long (far) infrared wavelengths uniformly, many materials selectively absorb short (near) infrared energy in bands. In process heating applications this selective absorption could be very critical to uniform and effective heating.

For process heating, it is recommended that the infrared source have a peak output wavelength that best matches the selective absorption band of the material being heated. When the major absorption wavelengths of the material being heated are known, the chart below provides guidance in selecting the most efficient heat source. The relative percentage of radiant energy emitted by specific source and falling in a particular wavelength range can be determined from the chart.

Example — Plastic materials are known to have high infrared absorption rates in wavelengths between 3 and 4 microns. Select a source which provides the most effective output to heat plastics in the 3 and 4 micron range.

1. **Enter Bottom of Chart** at 3 and 4 microns, read up to corresponding points on selected element curve (use 1400°F metal sheath in this example).
2. **From These Points,** move left to read the corresponding percentages (29% and 51%).
3. **The Difference** between these two values (22%) is the percentage of radiant energy emitted by the element within selected wavelengths limits.
4. **To Obtain** the maximum percentage of the energy emitted by a given element in the desired wavelength band, multiply the percentage in 3 above by the conversion efficiency for the selected element (comparison chart 56% x 22% = 12.2%).

In this example, a high temperature source (quartz lamp 4000°F) with a peak in the 1.16 micron range, while more energy conversion efficient, would not be as effective as a lower temperature metal sheath or panel heaters with a peak in the 2.8 to 3.6 micron range. Quartz tubes (1600°F) would provide similar peak wavelengths.



Characteristics of Commercially Used Infrared Heat Source

	Tungsten Filament		Nickel Chrome Resistance Wire			Wide Area Panels	
Infrared Source	**Glass Bulb**	**T3 Quartz Lamp**	**Quartz Tube**	**Metal Sheath**	**Ceramic**	**Ceramic Coated**	**Quartz Face**
Source Temperature (°F)	3000 - 4000°F	3000 - 4000°F	Up to 1600°F	Up to 1500°F	Up to 1600°F	200 - 1600°F	Up to 1700°F
Brightness	Intense white	Intense White	Bright Red to Dull Orange	Dull to Bright Red	Dark to Dull Red	Dark to Cherry Red	Dark to Cherry Red
Typical Configuration	G-30 Lamp	3/8" Dia. Tube	3/8 or 1/2" Tube	3/8 or 1/2" Tube	Various Shapes	Flat Panels	Flat Panels
Type of Source	Point	Line	Line	Line	Small Area	Wide Area	Wide Area
Peak Wavelength (microns)	1.16	1.16	2.55	2.68	3 - 4	2.25 - 7.9	2.5 - 6
Maximum Power Density	1 kW/ft^2	3.9 kW/ft^2	1.3 - 1.75 kW/ft^2	3.66 kW/ft^2	Up to 3.6 kW/ft^2	3.6 kW/ft^2	5.76 kW/ft^2
Watts per Linear Inch	N/A	100	34 - 45	45 - 55	N/A	N/A	N/A
Conversion Efficiency Infrared Energy	86%	86%	40 - 62%	45 - 56%	45 - 50%	45 - 55%	45 - 55%
Response Time Heat/Cool	Seconds	Seconds	1 - 2 Minutes	2 - 4 Minutes	5 - 7 Minutes	5 - 8 Minutes	6 - 10 Minutes
Color Sensitivity	High	High	Medium	Medium	Medium	Low to Medium	Low to Medium
Thermal Shock Resistance	Poor	Excellent	Excellent	Excellent	Good	Good	Good
Mechanical Ruggedness	Poor	Fair	Good	Excellent	Good	Good	Fair
Chromalox Model	—	QR	QRT	RAD, URAD	RCH	CPL, CPLI, CPH	CPHI

Technical Information

Radiant Infrared Heating - Process Applications

Application Parameters

Typical industrial applications of radiant heating include **curing** or **baking** (powders, paints, epoxies, adhesives, etc.), **drying** (water, solvents, inks, adhesives, etc.) and **product heating** (preheating, soldering, shrink fitting, forming, molding, gelling, softening, and incubating). The following are general guidelines that can be used in evaluating and resolving most radiant heating problems. Unfortunately, the process is so versatile and its applications so varied that it is not feasible to list solutions to every problem.

To determine heat energy requirements and select the best Chromalox infrared equipment for your application, it is suggested the problem be defined using a check list similar to below. Several of the key factors on the list are discussed on this and following pages:

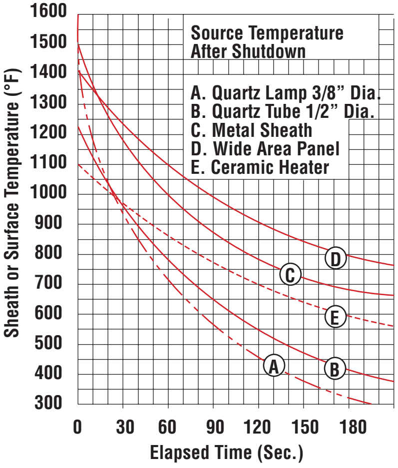
1. Product to be heated
2. Physical dimensions and weight/piece
3. Surface coating or solvents, if any
4. Infrared absorption characteristics
5. Production rate (lbs/hr, pieces/hr, etc.)
6. Work handling method during heating (continuous, batch or other)
7. Element response time (if critical)
8. Power level requirements in kW/ft^2 based on Time/Temperature relationship (if known)
9. Starting work temperature
10. Final work temperature
11. Ventilation (if present or required)
12. Available power supply
13. Space limitations

Infrared Absorption Characteristics — As previously discussed, many materials, particularly plastics, selectively absorb infrared radiation. The following chart provides data on some common plastic materials and the recommended source temperatures for thermoforming applications.

Plastic	Absorption Band(s) (microns)	Ideal Source Temperature (°F)
LPDE HDPE	3.3 - 3.9 3.2 - 3.7	877 - 1170 950 - 1170
PS	3.2 - 3.7 (6.4 - 7.4)	950 - 1170 245 - 355
PVC	1.65 - 1.8 (2.2 - 2.5)	2440 - 2700 1625 - 1910
PMMA PA-66	1.4 - 2.2 1.9 - 2.8 (3.4 - 5)	1910 - 3265 1405 - 2285 585 - 1075
Cellulose	2.2 - 3.6	990 - 1910
Acetate	(5.2 - 6)	440 - 545

Element Response Time — Some applications, such as continuous web heating of paper or plastic film, require quick shutdown of heaters in case of work stoppage. In these applications, residual radiation from the infrared heaters and associated equipment must be considered. Residual radiation from the element is a function of the operating temperature and mass. Quartz lamps and tubes have relatively low mass and the infrared radiation from the resistance wire drops significantly within seconds after shutdown. However, the surrounding quartz envelope acts as a secondary source of radiation and continues to radiate considerable energy. Metal sheathed elements have more mass and slightly slower response time. Wide area panels have the most mass and the slowest response time for both heat up and cool down. The following chart shows the average cool down rate of various sources after shutdown. Actual cool down of the source and work product will vary with equipment design, product temperature, ambient temperature and ventilation.

Source Temperature Vs. Time



Time-Temperature Relationship — A critical step in the evaluation of a radiant heating application is to determine the time necessary to develop work piece temperature and the elapsed time needed to hold temperature in order to obtain the desired results (curing or drying). The following chart shows time/temperature relationships for several typical infrared applications and materials.

Curing	Substrate	Surface Temp (°F)	W/In^2	Time (min)
Alkyd Paint	Steel	320	3.9	3
Epoxy Paint	Steel	356	8.1	5
Acrylic Paint	Steel	392	8.1	2
Powder Coat	Steel	400	13	6

Drying & Heating	Substrate	Surface Temp (°F)	W/In^2	Time (sec)
Glass Bottles	—	104	6.4	30
Adhesives	Paper	—	3.2	30
Heating				
PVC Shrinking	—	300	3.2	60
ABS Forming	—	340	9.7	—

Deriving Time-Temperature Information from Empirical Testing — If specific information is not readily available for a particular work product, a simple but effective test will usually provide enough preliminary data to proceed with a design. Place one or more radiant heaters in a position with the radiation directed at a work product sample. The distance between the face of the heater and the sample should approximate the expected spacing in the final application. Position the sample so that it is totally within the radiated area. Energize the heater(s) and record the time necessary to reach desired temperature. Calculate the W/in^2 falling on the work piece using the exposed area of the work product and the maximum kW/ft^2 at the face of the heater as listed in the product catalog page. If the data is not available and a sample test can not be performed, the following table provides a few suggested watt densities as guidance.

Application	W/In^2 on Work	
	Heat Up	Hold
Paint Baking	4-6	1 - 2
Metal Dry Off	15	8
Thermoforming	10 - 15	—
Fusing or Embossing (plastic films)	5-6	—
Silk Screen Drying	5-6	—

Contact your Local Chromalox Sales office for further information or assistance in determining time/temperature requirements for a particular application.

Power Level or Radiation Intensity — In most process applications, more than one radiant heater is needed to produce the desired results. When heaters are mounted together as close as possible, the net radiant output of the array is defined as the maximum power level or radiation intensity. The catalog pages for radiant heaters indicate the maximum kW/ft^2 at the face of each heater. Typical ranges for radiation intensity (power level) are as follows:

Radiant Intensity or Power Level	Heater Output (kW/Ft^2)
Low	1 - 2
Medium	2 - 3
High	Over 3

Technical Information

Radiant Infrared Heating - Process Applications

Determining kW Required — It is difficult to develop simple calculations for radiant heating applications because of the many variables and process unknowns. Design data gained from previous installations or from empirical tests is frequently the most reliable way of determining installed kW requirements. Total energy requirements can be estimated with conventional heat loss equations. The results of conventional equations will provide a check against data obtained from nomographs or empirical testing. As a minimum, conventional equations should include the following.

1. **Calculate the Sensible Heat** required to bring work to final temperature. Base calculations on specific heat and pounds of material per hour.
2. **Determine Latent Heat of Vaporization (when applicable).** Latent heat of vaporization is normally small for solvents in paints and is frequently ignored. However, when water is being evaporated, the kilowatt hours required may be quite significant.
3. **Ventilation Air (when applicable).** The rise in air temperature for work temperatures, 350°F or less, can usually be estimated as 50% of final work temperature rise. For higher work temperatures, assume air and work temperature are the same.
4. **Conveyor Belt or Chain Heat Requirements.** Assume temperature rise of conveyor to be the same as work temperature rise.
5. **Wall, Floor and Ceiling Losses for Enclosed Ovens.** For uninsulated metal surfaces, refer to Graph G-125S. For insulated walls, refer to Graph G-126S.
6. **Oven End Losses.** For enclosed ovens, this will depend on shape of end area and whether or not air seals are used. If silhouette shrouds are used, a safety factor of 10% is acceptable.
7. **The Sum of The Losses** calculated in 1-6 above will be the minimum total heat energy requirement based on conventional heat loss equations.

Infrared Heating Equations — Infrared energy requirements can also be estimated by using equations and nomographs developed specifically for infrared applications.

Product Heating — For product heating, the following equation can be used

$$\text{kW} = \frac{\text{Lbs/hr x } C_p \text{ x } \Delta T\,°\text{F}}{\text{3412 Btu/kW x Efficiency(RE) x VF x } \epsilon}$$

Where:
Lbs/hr = Pounds of work product per hour
C_p = Specific heat in Btu/lb/°F
ΔT = Temperature rise in °F
Efficiency (RE) = Combined efficiency of the source and reflector
VF = View Factor is the ratio of the infrared energy intercepted by the work product to the total energy radiated by the source. For enclosed ovens, use a factor of 0.9. For other applications, refer to the view factor table.
ϵ = Absorption (emissivity) factor of the work product

Drying & Solvent Evaporation — Removing solvent or water from a product requires raising the product temperature to the vaporization temperature of the solvent and adding sufficient heat to evaporate it. To calculate heat requirements for solvent evaporation, the following information must be known.

1. Pounds of solvent to be evaporated per hour
2. Pounds of work product per hour
3. Initial temperature of product and solvent
4. Specific heat of product
5. Specific heat of solvent
6. Vaporization temperature of solvent (ie: water = 212°F)
7. Heat of vaporization of solvent
8. Source/reflector efficiency
9. View factor
10. Absorption factor (emissivity)

WARNING — Hazard of Fire. Flammable solvents in the atmosphere constitute a fire hazard. When flammable volatiles are released in continuous process ovens, the National Fire Prevention Association recommends not less than 10,000 ft^3 of air be removed from the oven per gallon of solvent evaporated. Reference NFPA Bulletin 86 "Ovens and Furnaces", available from NFPA, P.O. Box 9101, Quincy MA 02269.

For drying, use the following equation.

$$\text{kW} = \frac{Q_{WP} + Q_S + Q_{LH}}{\text{3412 Btu/kW x Efficiency(RE) x VF x } \epsilon}$$

Where:
Q_{WP} = Btu required by work product to raise the temperature from initial to vaporization temperature
Q_S = Btu required by solvent to raise the temperature from initial to vaporization temperature
Q_{LH} = Btu required for the latent heat of the vaporization of the solvent
Efficiency (RE) = Combined efficiency of the source and reflector
VF = View Factor for enclosed ovens, use a factor of 0.9. For other applications, refer to the view factor table.
ϵ = Absorption (emissivity) factor of the work product

Controls — Most control systems for infrared process heating can be divided into two categories, open loop or manual systems and closed loop, fully automatic systems.

Open Loops or Manual Systems — The simplest and most cost effective control system is an input controllers (percentage timer) such as the Chromalox VCF Controller operating a magnetic contactor. The timer cycles the radiant heaters on and off for short periods of time (typically 15 - 30 seconds). This control system works best with metal sheath heaters, which have sufficient thermal mass to provide uniform radiation. It can be used with quartz tube or quartz lamp heaters by using special circuitry to switch from full to half voltage rather than full on and full off.

Closed Loop or Automatic Systems — Since infrared energy heats the work product by direct radiation, closed loop control systems that depend on sensing and maintaining air temperature are relatively ineffective (except in totally enclosed ovens). In critical applications where temperature tolerances must be closely held, non-contact temperature sensors operating SCR control panels are recommended. Non-contact temperature sensors can be positioned to measure only the work product temperature. Properly positioned, non-contact temperature sensors and SCR control panels can provide very accurate radiation and product temperature control.

Technical Information

Radiant Infrared Heating - Process Applications

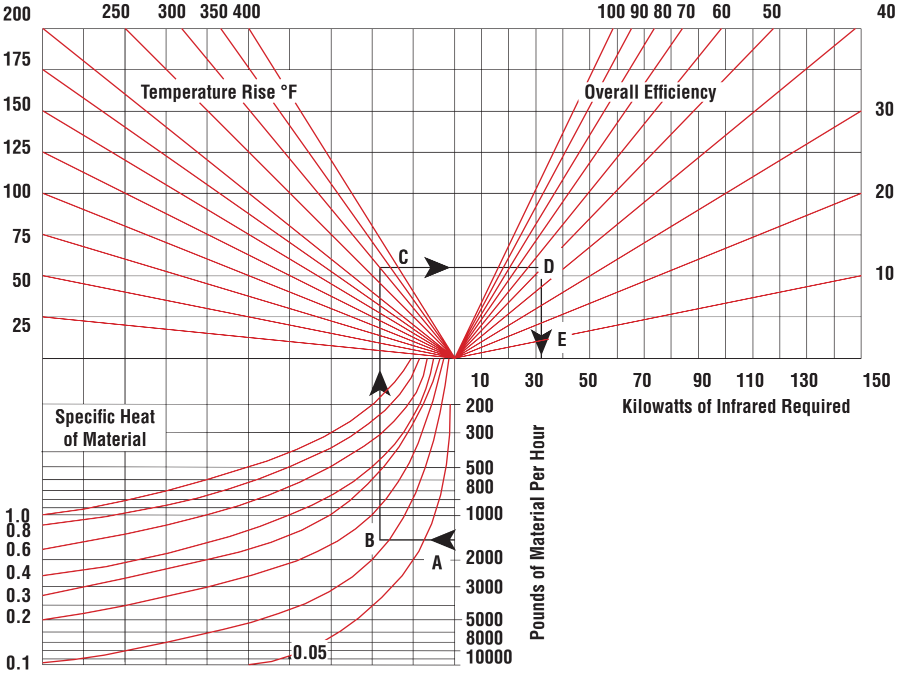
Nomograph for Product Heating — For product heating, the nomograph at the right can be used. The nomograph does not take into account heat energy requirements for air ventilation. To estimate the kW for total product heating:

1. **Determine** pounds of material per hour to be heated (A)
2. **Read across** to the specific heat of the material (B)
3. **Read up** to desired temperature rise in °F (C)
4. **Read across** to overall efficiency (D). Overall efficiency = Product Absorption Factor x View Factor x Source Efficiency. Determine Product Absorption Factor (surface emissivity) of the work product (ie: $\epsilon = 0.85$ for enamel sheet metal). Determine View Factor (use 0.9 as a view factor for well designed or enclosed ovens). Determine Source efficiency. Typical Source/Reflector efficiencies are:

Quartz Lamps	0.70 to 0.80
Quartz Tubes	0.60 to 0.70
Metal Sheath	0.55 to 0.65

5. **Read down** to Kilowatts required (E).

Estimating Total Kilowatts for Product Heating



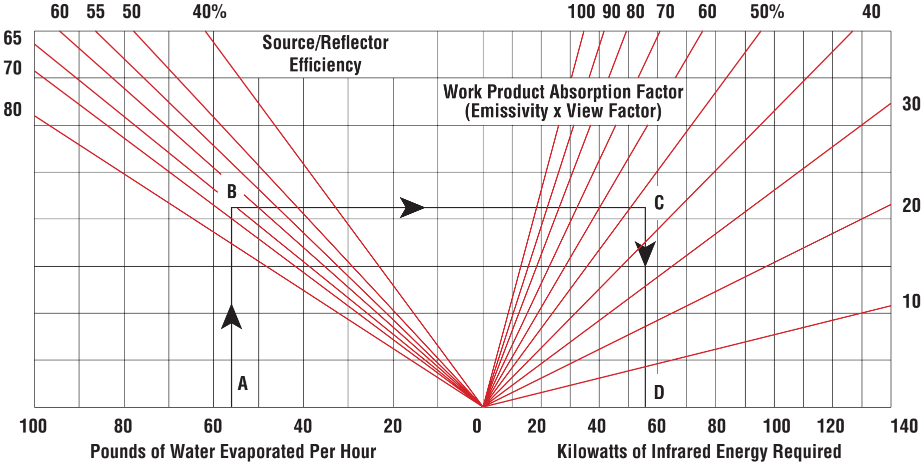
Nomograph for Drying — The nomograph to the right can be used to estimate Kilowatts required to evaporate water from the surfaces of work product. Graph is based on an initial starting product temperature of 70°F. It does not take into account heat energy requirements for air circulation or ventilation.

1. **Determine pounds** of water (solvent) per hour to be evaporated (A)
2. **Read up** to Source/Reflector efficiency (B). Depending on the configuration and cleanliness of the reflector, typical Source/Reflector efficiencies are:

Quartz Lamps	0.70 to 0.80
Quartz Tubes	0.60 to 0.70
Metal Sheath	0.55 to 0.65

3. **Read across** to Work Product Absorption Factor (C). This value is based on the emissivity of the work product surface (ie: $\epsilon = 0.85$ for enameled sheet metal) and the view factor of the oven or space. Use 0.9 as a view factor for well designed or enclosed ovens.
4. **Read down** to Kilowatts required (D).

Estimating Infrared Kilowatts for Drying



Note — To evaporate solvents other than water, calculate the energy required to heat the solvent to vaporization temperature using the weight, specific heat and temperature rise. Calculate the latent heat of vaporization and add to the energy required to heat the solvent to vaporization temperature.

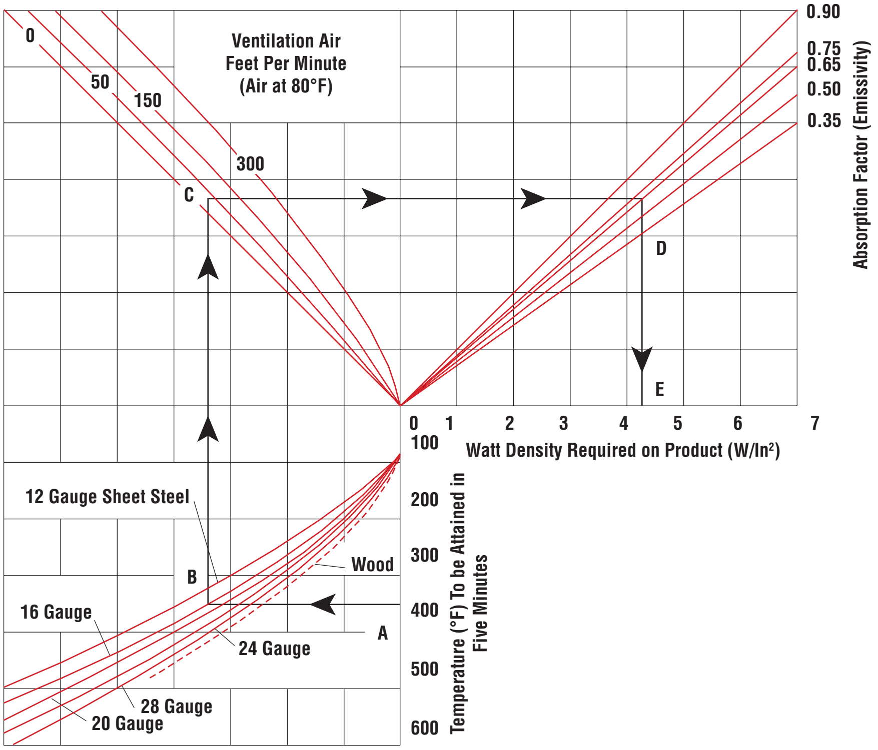
Technical Information

Radiant Infrared Heating - Process Applications

Baking & Curing — The nomograph to the right can be used to determine the watt density required on the work product for baking and curing of paints and coating. Lacquers are cured primarily by evaporation of the solvent and can be cured by infrared in 2 - 15 minutes. Enamels are cured primarily by polymerization and require a longer time (15 - 20 minutes). Varnishes, japans and house paints cure mainly by oxidation but can usually can be accelerated by infrared heating. To find approximate watt density needed for baking:

1. **Locate** temperature product is to reach in five minutes (A)
2. **Read across** to line representing gauge of the material being heated (B)
3. **Read up** to ventilation air in feet per minute over surface of the product (C). If not known, estimate feet per minute based on cubic feet per minute of ventilation or circulating air divided by the the approximate cross sectional area of the oven. In applications with no forced ventilation, use 2 - 5 fpm.
4. **Read right** to the absorption factor for the work product surface or coating (ie: ϵ = 0.85 for enameled sheet metal) (D)
5. **Read down** to watt density required on the product surface (E).

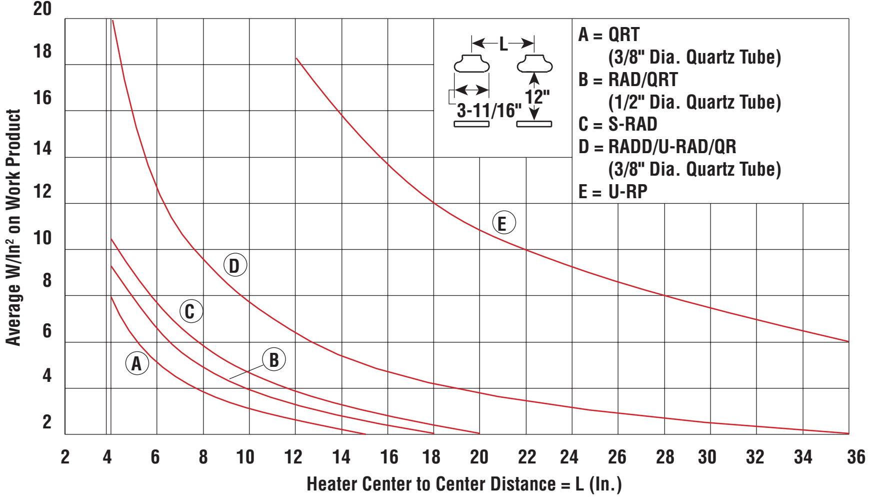
Estimating Watt Density for Curing or Baking



Determining Heater Fixture Spacing — Having determined the total required kilowatts and the desired W/in² on the work product, the next step is to deterine the spacing and the number of heaters. In most conveyor type oven applications, a 12" spacing from the face of the heater to the work product produces uniform distribution of the radiation. The graph to the right shows centerline to centerline spacing of Chromalox radiant heaters to obtain various intensities on the work based on a spacing of 12" from the face of the heater to the work product. Specific applications may require the distance to be increased or decreased.

The graph is applicable to line or point infrared sources installed in reflectors. Refer to view factor charts for ceramic heaters and flat panel infrared sources.

Intensity Vs. Spacing — Point & Line Infrared Sources

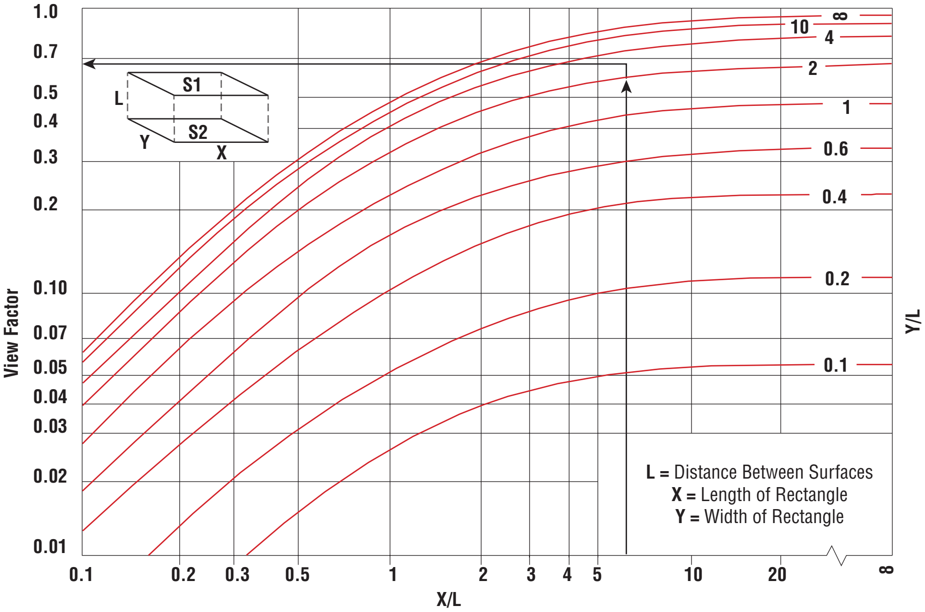


Technical Information

Radiant Infrared Heating - Process Applications

View Factor for Flat Panels — While the radiation pattern from line and point infrared sources can be controlled by reflectors, the radiation pattern from flat panels is diffused and the infrared energy is emitted from a large area. Consequently, the shape of the source and the target are a significant factor in determining the Watt density falling on the work product. For parallel surfaces in applications such as thermoforming or web heating, the incident energy falling on the work product is determined by a "View Factor". View factor is defined as the percentage or fraction of infrared energy leaving the surface of a flat panel (source) which is intercepted by the surface of the work product (target). The view factor for parallel surfaces (rectangles) can be determined from the graph. **Example** — Find the view factor for a 12 by 24" panel heater mounted 4" from a continuous web infrared drying application. X/L = 24" ÷ 4" = 6, Y/L = 12" ÷ 4" = 3. Read left from the intercept of X/L = 6 and Y/L = 3 with a view factor of 0.7.

View Factor for Two Parallel Surfaces



Radiant Oven Heating Example — A manufacturer of 66 gallon electric water heaters wishes to bake the paint on sheet metal jackets (open top and bottom) at 350°F. The jackets weigh 33 lbs, are 26" in diameter by 45" high with an outside area of 25.5 ft^2. The process requires 20 jackets be painted per hour. The jackets will be suspended from a conveyor chain on 9 ft centers and will be rotated as they move. The chain weighs 12 lbs/ft. The heaters will be installed in a tunnel oven with 2 inches of insulation and reflective walls. The oven is 8 ft long, 4 ft wide and 7 ft high and has end openings 3 ft by 6 ft. Preliminary test results show the jackets must be baked for six minutes for a satisfactory finish. The paint weighs 7.25 lbs/gal, contains 50% volatiles and covers 212 ft^2 per gallon. Assume a room temperature of 70°F
Specific heat of steel = 0.12 Btu/lb/°F
Boiling point of solvent = 170°F
Specific heat of solvent = 0.34 Btu/lb/°F
Latent heat of vaporization = 156 Btu/lb

Heat Required for Operation —

1. **Heat Absorbed by Jackets —** (20 jackets/hr x 33 lbs = 660 lbs/hr)

$$\frac{660 \text{ lbs/hr} \times 0.12 \text{ Btu/lb/°F} \times (350 - 70\text{°F})}{3412 \text{ Btu/kW}} = 6.5 \text{ kW}$$

2. **Heat Absorbed by Solvent —** Solvent volume

$$\frac{25.5 \text{ ft}^2 \times 20 \text{ jackets/hr} \times 50\%}{212 \text{ ft}^2\text{/gal}} = 1.20 \text{ gal/hr}$$

Heat required to heat solvent to 70°F

$$\frac{1.2 \text{ gph} \times 7.25 \text{ lb/gal} \times 0.34 \text{ Btu/lb} \times (170\text{-}70\text{°F})}{3412 \text{ Btu/kW}} = 0.1 \text{ kW}$$

Heat required to vaporize solvent

$$\frac{1.20 \text{ gph} \times 7.25 \text{ lb/gal} \times 156 \text{ Btu/lb}}{3412 \text{ Btu/kW}} = 0.4 \text{ kW}$$

Heat absorbed by solvent = 0.1 + 0.4 = 0.5 kW

3. **Heat Required by Ventilation Air —** (NFPA recommendation is a minimum of 10,000 cubic feet per gallon of solvent evaporated.)
Density of air = 0.080 lbs/ft^3
Specific heat of air = 0.240 Btu/lb/°F

Note — Ventilation air is heated by re-radiation and convection from the work, oven walls, etc. Air temperature is always less than the work temperature. Assume a 200°F air temperature.

Volume = 1.20 gph x 10,000 ft^3 = 12,000 ft^3/hr

$$\frac{12{,}000 \text{ ft}^3\text{/h} \times 0.08 \text{ lb/ft}^3 \times 0.24 \text{ Btu/lb/°F} \times (200\text{-}70\text{°F})}{3412 \text{ Btu/kW}}$$

Heat absorbed by ventilation air = 8.78 kW

4. **Conveyor Chain & Hangers —** Normally the conveyor chain is outside the radiation pattern of the heaters and is heated by convection from air in the tunnel. Since the heat absorbed by the air has already been accounted for, the heat absorbed by the conveyor may be ignored. (Conveyor speed should provide 6 minutes in the 8 foot heated area.)

Total Heat Absorbed —

6.5 kW + 0.5 kW + 8.8 kW = 15.8 kW

Heat Losses — Heat losses from oven surface with 2 inches of insulation (Graph G-126S) = 12 W/ft^2. Assume inside surface temperature of wall and ceiling = 250°F, ΔT = 180°F)
Wall area 7 ft x 8 ft x 2 ft = 112 ft^2
Ceiling and floor area 8 ft x 4 ft x 2 ft = 64 ft^2
Open tunnel ends = 3 ft x 6 ft x 2 ft = 36 ft^2

Heat loss from outside surfaces of oven

$$\frac{176 \text{ ft}^2 \times 12 \text{ W/ft}^2}{1000 \text{ W/kW}} = 2.1 \text{ kW/hr}$$

Heat loss from open oven ends (assume the open ends are equal to an uninsulated metal surface under the same conditions as the oven surfaces) (See Graph G-125S.)

$$\frac{36 \text{ ft}^2 \times 0.6 \text{ W/ft}^2 \times 180\text{°F}}{1000 \text{ W/kW}} = 3.89 \text{ kW/hr}$$

Total Heat Losses — 2.1 kW + 3.98 kW = 5.99 kW

Total Heat Capacity Required for Operation — 15.8 kW + 5.99 kW = 21.8 kW/hr

As with any process heat calculation, it is not possible to account for all the variables and unknowns in the application. A safety factor is recommended. For radiant heating applications, a safety factor of 1.4 is suggested.

Total Heat Required = 21.8 x 1.4 = 30.5 kWh

Technical Information

Radiant Infrared Heating - Comfort Heating

Indoor Spot Heating

Infrared spot heating of work stations and personnel in large unheated structures or areas has proven to be economical and satisfactory. The following guidelines may be used for spot heating applications (areas with length or width less than 50 feet).

1. **Determine** the coldest anticipated inside ambient temperature the system must overcome. If freeze protection is provided by another heating system, this temperature will be 40°F.
2. **Determine** the equivalent ambient temperature desired (normally 70°F is the nominal average).
3. **Subtract** 1 from 2 to determine the theoretical increase in ambient temperature (ΔT) expected from the infrared system. If drafts are present in the occupied area (air movement over 44 feet per minute (0.5 mph) velocity), wind shielding or protection from drafts should be considered.
4. **Determine** the area to be heated in ft^2. This is termed the "design or work area" (A_D) (Fig. 1).
5. **Multiply** the design area by one watt per square foot times the theoretical temperature increase (ΔT) desired as determined in Step 3 (minimum of 12 watts per square foot). The design factor of one watt per square foot density assumes a fixture mounting height of 10 feet. Add 5% for each foot greater than 10 feet in mounting height. Avoid mounting fixtures below 8 feet.
6. **Determine** fixture mounting locations
   a) In areas where the width dimension is 25 feet or less, use at least two fixtures mounted opposite each other at the perimeter of the area and tilted at an angle. This provides a greater area of exposure to the infrared energy by personnel in the work area. Tilt the fixtures so that the upper limit of the fixture pattern is at approximately six feet above the center of the work station area (Figure 2).
   b) When locating fixtures, be sure to allow adequate height clearance for large moving equipment such as cranes and lift trucks.
   c) Avoid directing infrared onto outside walls.
7. **Estimate** (tentatively) the radiated pattern area. Add length of fixture to the fixture pattern width (W) to establish pattern length (L). Pattern Area = L x W (Fig. 3).

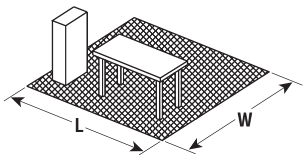


Figure 1 — Design Area

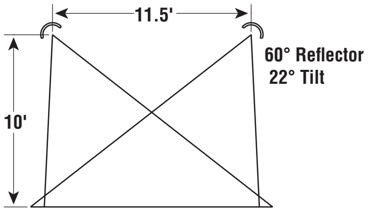


Figure 2 — Tilted Infrared Fixtures for Spot Heating

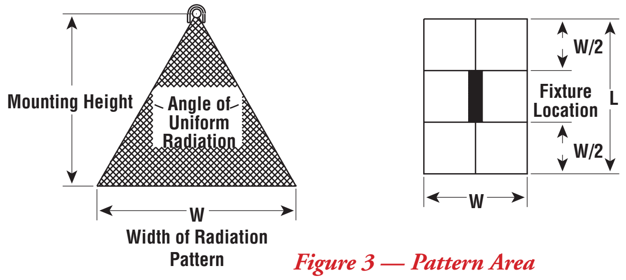


Figure 3 — Pattern Area

8. **Divide** the design area (Step 4) into the pattern area (Step 7).

   $$Q = \frac{\text{Pattern Area}}{\text{Design Area}}$$

   If the pattern area is equal to or greater than the design area, quotient (Q) will be equal to or greater than 1 and coverage is adequate. If Q is less than 1, the design area exceeds the pattern area of individual fixtures. Adjust the heater locations and patterns or add additional fixtures with patterns overlapping as necessary, to ensure adequate coverage.
9. **Multiply** quotient (Q in Step 8) by the increase in theoretical temperature (ΔT of Step 3) by the design area (A_D of Step 4) to determine the amount of radiation to be installed.

   $$\text{Radiation (Watts)} = Q \times \Delta T \times A_D$$
10. **Many Types** of radiant heaters are available for comfort heating applications including ceiling, wall and portable floor standing models. Choose specific fixtures from the product pages. It is preferred that half the wattage requirements be installed on each side of the work station in the design area.

Controls — Manual control by percentage timers may be adequate for a small installation. To provide better control of comfort levels in varying ambient temperatures, divide the total heat required into two or three circuits so that each fixture or heating element circuit can be switched on in sequence. Staging can be accomplished by using multistage air thermostats set at different temperatures.

Indoor Area Heating

In many industrial environments, area heating (areas with length or width greater than 50 ft) can be accomplished economically with multiple infrared heaters. For quick estimates, determine the minimum inside temperature and use a factor of 0.5 watts per square foot of design area for each degree of theoretical temperature. If the calculated heat loss of the structure, including infiltration or ventilation air, is less than the quick estimate, select the lower value. Locate heaters uniformly throughout the area with at least a 30% overlap in radiation pattern.

Outdoor Spot Heating

The same guidelines outlined under Indoor Spot Heating should be followed except that watts per square foot for each degree of theoretical ambient temperature increase should be doubled (approximately 2 watts per square foot for each 1°F). This factor applies to outdoor heating applications with little or no wind chill effect on personnel. If wind velocities are a factor in the application, determine the equivalent air temperature from the Wind Chill Chart in NEMA publication HE3-1971 or other information source.

Note — Increasing the infrared radiation to massive levels to offset wind chill can create discomfort and thermal stress. In outdoor exposed applications, a wind break or shielding is usually more effective.

Technical Information

Electrical Fundamentals & Three Phase Calculations

Ohm's Law

The relationship between Wattage (heat) output and the applied Voltage of electric resistance heating elements is determined by a precise physical rule defined as Ohm's Law which states that the current in a resistance heating element is directly proportional to the applied Voltage. Ohm's Law is traditionally expressed as:

$$I = \frac{E}{R}$$

Where: I = Amperes (Current)
E = Voltage
R = Ohms (Resistance)

The same equation using the conventional abbreviation for voltage is:

$$I = \frac{V}{R}$$

Where: I = Amperes (Current)
V = Voltage
R = Ohms (Resistance)

An unknown electrical value can be derived by using any two known values in one of the variations of Ohm's Law shown at the right.

Voltage & Wattage Relationships

An electric resistance element only produces rated Wattage at rated Voltage. It is common for electric heating elements and assemblies to be connected to a wide range of operating Voltages. Since the Wattage output varies directly with the ratio of the square of the Voltages, the actual Wattage can be calculated for any applied Voltage. The relationship is expressed by the equation below,

$$W_A = W_R \times \left(\frac{V_A^2}{V_R^2}\right)$$

Where: W_A = Actual Wattage
W_R = Rated Wattage
V_A = Applied Voltage
V_R = Rated Voltage

Three Phase Equations (Balanced)

Ohm's Law, as stated above, applies to electrical resistance elements operated on single phase circuits. Ohm's Law can be modifed to calculate three phase values by adding a correction factor for the phase Voltage relationships. The three phase equations shown can be applied to any balanced Delta or Wye circuit. The terms used in the equations are identified below:

V_L = Line Voltage
V_P = Phase Voltage
I_L = Line Current (Amps)
I_P = Phase Current (Amps)
W_T = Total Watts
R_1 = $R_2 = R_3$ = Element Resistance
W_C = Wattage per Circuit (Equal Circuits)
R_C = Circuit Resistance in Ohms Measured Phase to Phase

OHM'S LAW

VOLTS

VOLTS = $\sqrt{\text{WATTS X OHMS}}$

VOLTS = $\frac{\text{WATTS}}{\text{AMPERES}}$

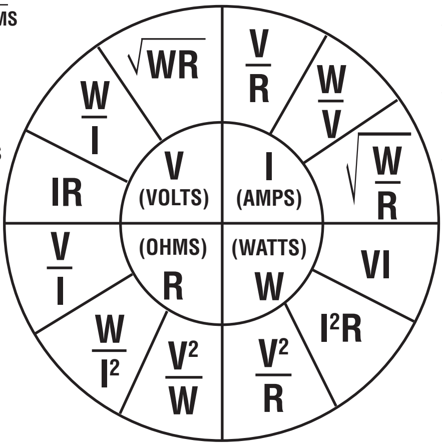
VOLTS = AMPERES X OHMS

AMPERES

AMPERES = $\frac{\text{VOLTS}}{\text{OHMS}}$

AMPERES = $\frac{\text{WATTS}}{\text{VOLTS}}$

AMPERES = $\sqrt{\frac{\text{WATTS}}{\text{OHMS}}}$



OHMS

OHMS = $\frac{\text{VOLTS}}{\text{AMPERES}}$

OHMS = $\frac{\text{WATTS}}{\text{AMPERES}^2}$

OHMS = $\frac{\text{VOLTS}^2}{\text{WATTS}}$

WATTS

WATTS = VOLTS x AMPERES

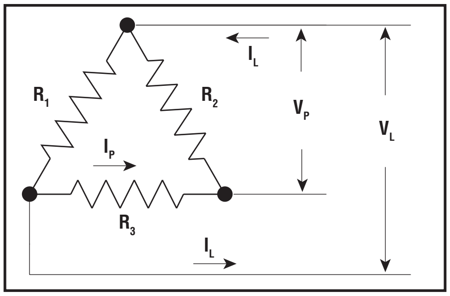
WATTS = AMPERES² x OHMS

WATTS = $\frac{\text{VOLTS}^2}{\text{OHMS}}$

Percent of Rated Wattage for Various Applied Voltages

Applied Voltage	Rated Voltage													
	110	115	120	208	220	230	240	277	380	415	440	460	480	575
110	100	91	84	28	25	23	21	16	8.4	7.0	6.2	5.7	5.2	3.7
115	109	100	92	31	27	25	23	17	9.0	7.6	6.7	6.2	5.7	4.0
120	119	109	100	33	30	27	25	19	10	8.4	7.4	6.8	6.3	4.3
208	—	—	300	100	89	82	75	56	30	25	22	20	19	13
220	—	—	—	112	100	91	84	63	34	28	25	23	21	15
230	—	—	—	122	109	100	92	69	37	31	27	25	23	16
240	—	—	—	133	119	109	100	75	40	33	30	27	25	17
277	—	—	—	—	—	—	133	100	53	45	40	36	33	23
380	—	—	—	—	—	—	—	188	100	84	74	68	63	44
415	—	—	—	—	—	—	—	—	119	100	89	81	75	52
440	—	—	—	—	—	—	—	—	—	112	100	91	84	58
460	—	—	—	—	—	—	—	—	—	123	109	100	92	64
480	—	—	—	—	—	—	—	—	—	—	119	109	100	70
550	—	—	—	—	—	—	—	—	—	—	156	143	131	91
575	—	—	—	—	—	—	—	—	—	—	171	156	144	100
600	—	—	—	—	—	—	—	—	—	—	186	170	156	109

3Ø Delta

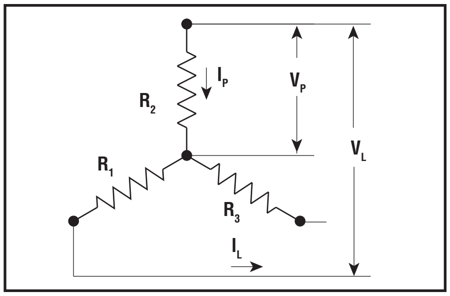


$V_P = V_L$
$W_T = 1.73\ I_L \times V_L$
$I_P = I_L \div 1.73$
$W_C = 1.73\ I_L \times V_L \div \#$ Circuits
$R_C = (2 \times V_L^2) \div W_C$

$V_L = V_P$
$W_T = 3\ (V_L^2 \div R_1)$
$I_L = I_P \times 1.73$
$R_C = V_L^2 \div 0.5 W_C$

Note — For Open Delta connections, see next page.

3Ø Wye



$V_P = V_L \div 1.73$
$W_T = 1.73\ I_L \times V_L$
$I_P = I_L$
$W_C = 1.73\ I_L \times V_L \div \#$ Circuits
$R_C = (2 \times V_L^2) \div W_C$

$V_L = V_P \times 1.73$
$W_T = V_L^2 \div R_1$
$I_L = I_P$
$R_C = V_L^2 \div 0.5\ W_C$

Note — For Open Wye connections, see next page.

Technical Information

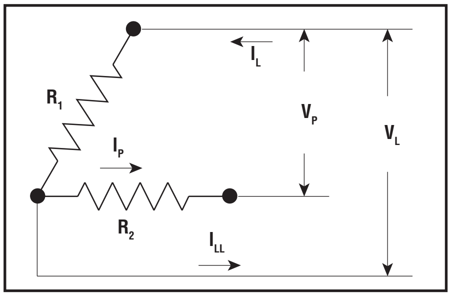
Three Phase Equations & Heater Wiring Diagrams

Open Delta & Wye

Three phase heating circuits are most efficient when operated under balanced conditions. If it is necessary to operate an unbalanced load, the equations below can be used to calculate the circuit values for open three phase Delta or Wye circuits. The terms used in the equations are identified below:

V_L = Line Voltage
V_P = Phase (Element) Voltage
I_L = Line Current (Amps)
I_{LL} = Line Current (Unbalanced Phase)
I_P = Phase Current (Amps)
W_T = Total Watts
$R_1 = R_2 = R_3$ = Element Resistance
R_C = Circuit Resistance in Ohms Measured from Phase to Phase

3Ø Open Delta

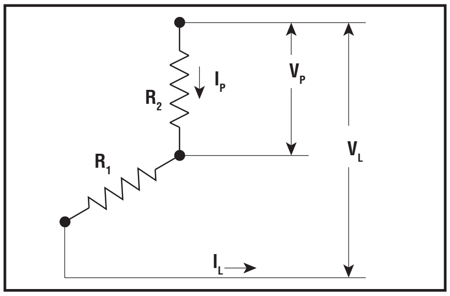


$V_P = V_L$
$W_T = 2V_L \times I_L$
$I_P = I_L$
$W_C = 2V_P \times I_P$

$V_L = V_P$
$W_T = 2 (V_L^2 \div R_1)$
$I_L = I_P$
$I_{LL} = 1.73 \times I_P$

The loss of a phase or failure of an element in a three (3) element Delta circuit will reduce the wattage output by 33%.

3Ø Open Wye



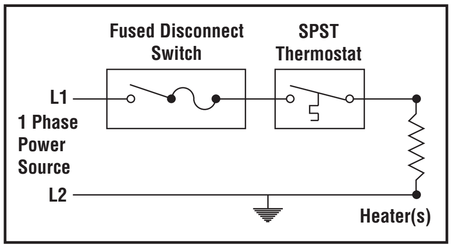
$V_P = V_L \div 2$
$W_T = I_L \times V_L$
$I_P = I_L$
$R_C = V_L^2 \div W_C$

$V_L = V_P \times 2$
$W_T = V_L^2 \div 2R_1$
$I_L = I_P$

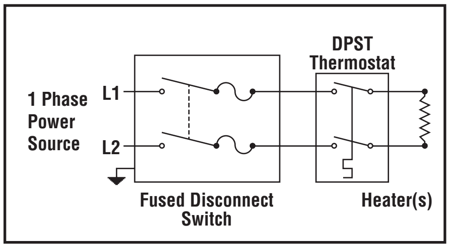
The loss of a phase or failure of an element in a three (3) element Wye circuit will reduce the wattage output by 50%. Heating elements are basically in series on single phase power.

Typical Heater Wiring Diagrams

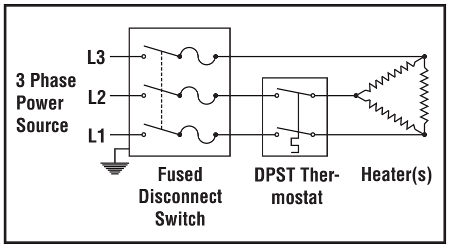
The following diagrams show typical heater wiring schematics.



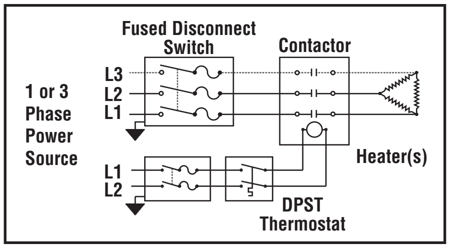
Single Phase 120 VAC heater circuit where line voltage and current do not exceed thermostat rating.



Single Phase AC circuits where line voltage and current do not exceed thermostat rating.

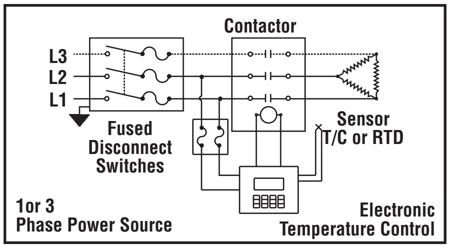


Three Phase AC heater circuit where line voltage and current do not exceed thermostat rating. Circuit does not have a “positive” off.

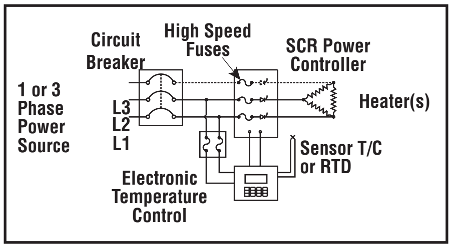


Single or Three Phase AC heater circuit where line voltage and current exceed thermostat rating. Separate control circuit can use a single pole or double pole thermostat. Control circuit requires over-current protection.

WARNING — Hazard of Electric Shock. Any installation involving electric heaters must be effectively grounded in accordance with the National Electrical Code to eliminate shock hazard.



Single or Three Phase AC heater circuit using electronic temperature controllers and contactors. Controller and contactor holding coil must be rated for the same voltage as the heater circuit. Control circuit requires over- current protection.



Single or Three Phase AC heater circuit using an electronic temperature controller and a SCR (solid state) power controller. Controller must be rated the same voltage as the heater circuit. Control circuit requires over-current protection. All electrical wiring to electric heaters must be installed in accordance with the National Electrical Code or local electrical codes by a qualified person.

Wiring & Ambient Temperatures

Ambient temperatures must be considered when selecting wiring materials for electric heater circuits. Heating equipment and processes may cause associated wiring to operate well above ambient temperatures. These temperatures may result from heat conducted from the heater terminals, radiation from heated surfaces or simply high ambient air temperatures. Nickel plated copper or nickel alloy conductors with high temperature insulation should always be used in high temperature areas. Outside these areas, conventional wiring materials can usually be used. 60°C building wire is usually not suitable unless otherwise indicated.

Wiring in Severe Conditions

Moist or wet locations require gasketed terminal and junction boxes to protect equipment and wiring. Rigid conduit is recommended. Hazardous Locations require the use of approved explosion-proof terminal and junction boxes. Rigid conduit or mineral insulated (MI) cable is mandatory in Division 1 areas. Some Hazardous Locations may require conduit seals (EYS) adjacent to the equipment.

Technical Information

Wiring Practices for Electric Heaters

Wire Insulation & Conductors

The selection of wiring materials to be used in a particular application depends upon the service Voltage and the anticipated operating temperatures. The table below lists some of the more common code wire constructions according to their temperature limitations. Insulated wires should be derated for elevated ambient temperatures and should never be used above their temperature rating. The operating temperature of unplated copper wire should be limited to 200°C (392°F) maximum. A complete listing of wire construction and allowable current carrying capacities is shown in the National Electric Code Article 310.

General Purpose Wiring

Max. Conductor Temperature		Wire Type (600V)	Construction (Copper Conductors)
°C	°F		
60	140	TW	Thermoplastic
75	167	RHW THW	Rubber Thermoplastic
90	194	RHH	Heat Resistant Rubber
		THWN	Heat Resistant Thermoplastic
		XHHN	Heat Resistant Cross-link Thermoplastic
		MTW	Heat Resistant Cross-link Thermoplastic
200	392	FEP	Teflon®

High Temperature Wiring Materials

Max. Conductor Temperature		Wire Type (600V)	Construction (Nickel Plated Copper or Nickel Conductors)
°C	°F		
250	482	TGT TGGT	Teflon® - Glass - Teflon®
450	842	MGS MGT	Mica - Glass - Silicone Mica - Glass - Teflon®
594	1100	Bare	Maganese Nickel Wire or Bus Bars with Ceramic Insulators

Note — High temperature wiring materials are available for field application.

Contactor Sizing

Contactors are normally rated for inductive and resistive loads. Most electric resistance heaters have negligible inrush or inductive current. Select contactors based on resistive load ratings. Using the formulas shown in the paragraphs on wire sizing to determine the amp load per pole (phase). Select a contactor with the next highest current rating. Use a two pole contactor for single phase (two-wire) power and a three pole contactor for balanced Delta or Wye three phase loads. For heater loads with high inrush current, refer to product data information for maximum amperage.

Thermocouple Wire & Cable

Thermocouples and extension lead wires are color coded to aid in identification and to avoid inadvertent cross wiring. The following charts indicate the colors used of different alloys.

Thermocouple Color Coding

Type	Positive Color (+)	Alloys
J	White	Iron/Constantan
K	Yellow	Chromel/Alumel
T	Blue	Copper/Constantan
E	Purple	Chromel/Constantan
R	Black	Platinum/Platinum (with 13% Rhodium)
S	Black	Platinum/Platinum (with 6% Rhodium)
N	Orange	Nicrosil/Nisil

Note — Negative (-) conductor identified with red colored insulation.

Thermocouple Extension Wire Colors

Type	Positive	Negative	Color Overall	Positive Color (+)
T	TPX	TNX	Blue	Blue
J	JPX	JNX	Black	White
E	EPX	ENX	Purple	Purple
K	KPX	KNX	Yellow	Yellow
R or S	SPX	SNX	Green	Black
B	BPX	BNX	Gray	Gray

Note — Negative (-) conductor identified with red colored insulation.

Electrical Noise & Controls

Electrical "noise" refers to extraneous electrical voltages that interfere with legitimate control signals. Most electrical noise is introduced by electromagnetic coupling with fluorescent lights, contactors, power wiring, switches and other arcing devices. Shield control circuit wiring and keep thermocouple wires separate from power wiring. Trace shielded thermocouple lead wires in a separate conduit for maximum protection.

Temperature Limits for Controls

Most mechanical controls and thermostats (control bodies) can withstand a wide range of ambient temperatures ranging from below freezing to over 140°F. Electronic controls, transformers, contactors and other electrical devices are more temperature sensitive and extreme temperatures will usually shorten the life of the component. Most electrical and electronic equipment will function accurately in ambient temperatures ranging from about 30°F to about 130°F. Triacs and SCR controls frequently require special cooling for full load ratings when operated over 120°F. Refer to the installation instructions or contact the device manufacturer for recommendations.

Wiring Hints for Electric Heaters

The following are some general recommendations for wiring electric heating elements and assemblies. These recommendations are only suggestions and are not intended to conflict with the National Electric Code or local codes.

WARNING — Hazard of Electric Shock. Any installation involving electric heaters must be effectively grounded in accordance with the National Electrical Code to eliminate shock hazard. All electrical wiring to electric heaters must be installed in accordance with the National Electrical code or local electrical codes by a qualified person.

1. Repetitive heating and cooling can cause wiring connections to loosen over time. High amperage through a loose terminal can cause overheating and terminal failure. All heater terminal connections should be tightened to a maximum torque consistent with terminal strength. Use a second wrench or pliers to prevent twisting heater terminals.
2. Use stranded wire in applications where the power wires to heater terminal connections may be subject to movement. When using solid wire or bus bar on heater terminals, provide expansion loops between points of support to minimize damaging stresses due to expansion and contraction.
3. Solder or silver braze lead connections to heating elements that may be subject to extreme temperatures or vibration. Use a minimum of flux to complete the connection and keep flux from contaminating the heating element. Remove residual flux to prevent corrosion of the electrical joint.
4. Keep thermostat capillary tubing and thermocouple wiring clear of heater terminals to prevent accidental short circuits. Sleeving or insulated tubing is recommended.
5. Use wiring suitable for the anticipated operating temperatures. Unless the heater is specifically marked for use with low temperature copper wiring, high temperature alloy conductors are recommended for connections to the heater terminals.
6. Do not use rubber, wax impregnated or plastic covered wire inside terminal enclosures of heaters in high temperature applications. These insulations will deteriorate and give off fumes which can contaminate the heating elements and cause short circuits.

Technical Information

Wiring Practices for Electric Heaters *(cont'd.)*

Selecting Wire Size (AWG)

The size (wire gauge) of the electrical conductor for a particular application will depend upon the Amperage (current) which the heating load will draw from the power source. Current can be calculated by Ohm's Law. To calculate amperage, use the following formulas. On a single phase (two-wire) power supply, the amperage per line is calculated by:

$$\text{1 Ph Amperage} = \frac{\text{Total Circuit Wattage}}{\text{Line Voltage}}$$

On three phase power circuits with balanced Delta or Wye heating loads, line amperage is calculated by:

$$\text{3 Ph Amperage} = \frac{\text{Total Circuit Wattage}}{\text{Line Voltage x 1.73}}$$

Table II lists amperages for common kW ratings.

Allowable Ampacities

Once the load current has been determined, wire size for the calculated amperage may be selected from tables in Article 310 of the National Electrical Code (NEC). As a guide, Table III at the right lists recommended ampacities for the more common insulated wires for high temperature applications. Current ratings for 90°C wire in a 30°C ambient are included for reference.

Corrections for Elevated Ambient Temperatures

The recommended current carrying capacities of 200°C and 250°C wire are valid if conductor temperatures do not exceed 104°F (40°C). Operating temperatures in excess of 104°F (40°C) require the application of a temperature correction factor for the corresponding wire.

Example — Size 14 AWG, type TGT wire is capable of handling 39 Amperes at 104°F (40°C) but must be reduced to 0.85 (85%) or 33 Amperes when operated at 212°F (100°C).

Multiple Insulated Wires in Conduit

The wire size selected above may be used in the heating circuit with three (3) wires enclosed in rigid or flexible conduit to protect the wiring. If more than 3 conductors are installed in the same conduit, another current correction factor must be used. For 4 to 6 conductors in a single conduit use 80% of the recommended current-carrying capacity. For 7 to 24 conductors use 70%.

Table II — Amperage (Current) for Typical kW Heater Ratings

	Single Phase					Three Phase Balanced Load				
kW	**120V**	**208V**	**240V**	**440V**	**480V**	**208V**	**240V**	**440V**	**480V**	**575V**
1	8.4	4.8	4.2	2.3	2.1	2.8	2.5	1.4	1.3	1.0
2	16.7	9.7	8.4	4.6	4.2	5.6	4.9	2.7	2.5	2.0
3	25.0	14.5	12.5	6.9	6.3	8.4	7.3	4	3.7	3.0
4	33.4	19.3	16.7	9.1	8.4	11.2	9.7	5.3	4.9	4.0
5	41.7	24.1	20.9	11.4	10.5	13.9	12.1	6.6	6.1	5.0
6	50.0	28.9	25.0	13.7	12.5	16.7	14.5	7.9	7.3	6.0
7.5	62.5	36.1	31.3	17.1	15.7	20.9	18.1	9.9	9.1	7.5
10	83.4	48.1	41.7	22.8	20.9	27.8	24.1	13.2	12.1	10.0
12	100.0	57.7	50.0	27.3	25	33.4	29	15.8	14.5	12.1
15	125.0	72.2	62.5	34.1	31.2	41.7	36.2	19.7	18.1	45.1
20	167.0	96.2	83.4	45.5	41.7	55.6	48.2	26.3	24.1	20.1
25	209.0	121	105	56.9	52.1	69.5	60.3	32.9	30.1	25.1
30	—	145	125	68.2	62.5	83.4	72.3	39.4	36.2	30.2
50	—	241	209	114	105	139	121	65.7	60.3	50.3
75	—	—	313	171	157	209	181	98.6	90.4	75.4
100	—	—	417	228	209	278	241	132	121.0	100.0

Table III — Allowable Ampacities

Three Insulated Conductors in a Raceway or Conduit				Single Conductor[1,2] in Free Air (200°C Ambient)		
Conductor Type	Copper	Copper	Nickel or Nickel Coated Copper	Nickel Coated Copper	Nickel	
Insulation Type	THHN XHHW MTW	FEP PFA SRG	TGT TGGT TFE	MGT MGS	MGT MGS	
Ambient Temp.	30°C (86°F)	40°C (104°F)	40°C (104°F)	200°C (392°F)	200°C (392°F)	
Maximum Conductor Temperature (Insulation Limits)						
Size AWG	90°C (194°F)	200°C (392°F)	250°C (482°F)	450°C (842°F)	450°C (842°F)	
14	25	36	39	44	23	
12	30	45	54	58	31	
10	40	60	73	77	42	
8	55	83	93	100	53	
6	75	110	117	—	—	
Correction Factors for Elevated Ambient Temperatures						
Ambient (°C)	For ambient temperature exceeding the values in the above table, multiply the allowable ampacities by the appropriate factor below.					Ambient (°F)
36 - 40	0.91	1.00	1.00	—	—	96 - 104
41 - 45	0.87	0.97	0.98	—	—	105 - 113
46 - 50	0.82	0.96	0.97	—	—	114 - 122
51 - 55	0.76	0.95	0.95	—	—	123 - 131
56 - 60	0.71	0.94	0.94	—	—	132 - 140
61 - 70	0.58	0.9	0.93	—	—	141 - 158
71 - 80	0.41	0.87	0.9	—	—	159 - 176
81 - 90	—	0.83	0.87	—	—	177 - 194
91 - 100	—	0.79	0.85	1.22	—	195 - 212
101 - 120	—	0.71	0.79	1.19	—	213 - 248
121 - 140	—	0.61	0.72	1.16	1.16	249 - 284
141 - 160	—	0.5	0.65	1.12	1.12	285 - 320
161 - 180	—	0.35	0.58	1.06	1.06	321 - 356
181 - 200	—	—	0.49	1.00	1.00	357 - 392
201 - 225	—	—	0.35	0.92	0.92	393 - 437
226 - 250	—	—	—	0.87	0.87	438 - 542
250 - 300	—	—	—	0.70	0.70	543 - 572
300 - 350	—	—	—	0.49	0.49	573 - 662

1. Data derived or extrapolated from values and criteria set forth in NEC Article 310.
2. MGT & MGS insulated wire is intended to be used for interconnection of strip heaters and elements located in high temperature ambients and is not intended for general purpose wiring. Do not use these Amp ratings for three insulated conductors inside raceways or conduits.

Reference Data

Pressure-Temperature Ratings of Common Flange Materials

Recommended Maximum Pressure-Temperature Ratings[1] for Catalog Flange Immersion & Circulation Heaters[2]

Temp. (°F)	Class 150 (Pressures in psig)							Class 300 (Pressures in psig)							Class 600 (Pressures in psig)							Temp (°F)
	B-16.5 Material Group Number																					
	1.1	1.9	2.1	2.2	2.3	2.4	2.5	1.1	1.9	2.1	2.2	2.3	2.4	2.5	1.1	1.9	2.1	2.2	2.3	2.4	2.5	
			Austenitic Steels							Austenitic Steels							Austenitic Steels					
	Carbon Steel	Alloy Steel 1-¼ Cr-½ Mo	Type 304	Type 316	Type 304L 316L	Type 321	Type 347, 348	Carbon Steel	Alloy Steel 1-¼ Cr-½ Mo	Type 304	Type 316	Type 304L 316L	Type 321	Type 347, 348	Carbon Steel	Alloy Steel 1-¼ Cr-½ Mo	Type 304	Type 316	Type 304L 316L	Type 321	Type 347, 348	
-20 to 100	285	290	275	275	230	275	275	740	750	720	720	600	720	720	1,480	1,500	1,440	1440	1,200	1,440	1,440	-20 to 100
200	260	260	235	240	195	235	245	675	710	600	620	505	610	635	1,350	1,425	1,200	1240	1,015	1,220	1,270	200
300	230	230	205	215	175	210	225	655	675	530	560	455	545	590	1,315	1,345	1,055	1120	910	1,090	1,175	300
400	200	200	180	195	160	190	200	635	660	470	515	415	495	555	1,270	1,315	940	1030	825	990	1,110	400
500	170	170	170	170	145	170	170	600	640	435	480	380	460	520	1,200	1,285	875	955	765	915	1,035	500
600	140	140	140	140	140	140	140	550	605	415	450	360	435	490	1,095	1,210	830	905	720	875	985	600
650	125	125	125	125	125	125	125	535	590	410	445	350	430	480	1,075	1,175	815	890	700	855	960	650
700	110	110	110	110	110	110	110	535	570	405	430	345	420	470	1,065	1,135	805	865	685	840	935	700
750	95	95	95	95	95	95	95	505	530	400	425	335	415	460	1,010	1,065	795	845	670	830	920	750
800	80	80	80	80	80	80	80	410	510	395	415	330	415	455	825	1,015	790	830	660	825	910	800
850	65	65	65	65	65	65	65	270	485	390	405	320	410	445	535	975	780	810	645	815	890	850
900	50	50	50	50	—	50	50	170	450	385	395	—	405	430	345	900	770	790	—	810	865	900
950	35	35	35	35	—	35	35	105	380	375	385	—	385	385	205	755	750	775	—	775	775	950
1000	20	20	20	20	—	20	20	50	225	325	365	—	355	365	105	445	645	725	—	715	725	1000
1050									140	310	360	—	345	360	—	275	620	720	—	695	720	1050
1100									95	260	325	—	300	325	—	190	515	645	—	605	645	1100
1150									50	195	275	—	235	275	—	105	390	550	—	475	550	1150
1200									35	155	205	—	180	170	—	70	310	410	—	365	345	1200
1250									—	—	—	—	—	125	—	—	220	365	—	280	245	1250
1300									—	85	140	—	105	95	—	—	165	275	—	210	185	1300
1350									—	60	105	—	80	70	—	—	125	205	—	165	135	1350
1400									—	50	75	—	60	50	—	—	90	150	—	125	105	1400
1450									—	35	60	—	50	40	—	—	70	115	—	95	80	1450
1500									—	25	40	—	40	35	—	—	50	85	—	75	70	1500

Material Groups	Notes
1.1 A-105, A516-70	A, B
1.1 A350-LF2	C
1.9 A182-F11, A182-F12	D
2.1 A182-F304, F304H and A240-304	—
2.2 A182-F316, F316H and A240-316	—
2.3 A182-F304L, F316L and A240-304L	E, F
2.4 A182-F321, F321H and A240-321, 321H	G
2.5 A182-F347, F347H and A240-347, 347H	H
	—

1. The above table is in accordance with ANSI B16.5, 1988 Edition. For other materials, critical applications or for higher pressure-temperature requirements, refer to ANSI Std. B16.5 or contact your Local Chromalox Sales office.
2. Pressure-temperature ratings for ASME pressure vessels and flanges may vary from the values shown in the above table due to Code requirements, re-inforcement and ligament calculations. Contact your Local Chromalox Sales office for further information and specific recommendations for ASME Coded flanges and heaters.

Other Notes —

A. Not recommended for prolonged use above 800°F.
B. Do not use A105 flanges above 1000°F or A516-70 plate over 850°F.
C. Do not use A350-LF2 flanges above 650°F.
D. Not recommended for prolonged use above 1100°F.
E. Do not use A182-F304L flanges or A240-304L plate above 800°F.
F. Do not use A182-F316L flanges or A240-316L plate above 850°F.
G. Do not use A182-F321 flanges or A240-321 over 1000°F.
H. Do not use A182-F347 flanges or A240-347 plate above 1000°F.

Pipe Specifications — Standard (Schedule 40) Steel & Stainless Pipe

Nominal Pipe Size	Pipe Schedule	Outside Dia. (In.)	Wall Thickness (In.)	Inside Dia. (In.)	Inside Area (In^2)	Weight (Lbs/Ft.)	Volume (Gal/Ft.)	Wt. Water (Lbs/Ft.)	Thds/In. (NPT)
1/8	Sch 40 (Std)	0.405	0.068	0.269	0.0568	0.245	0.0030	0.0246	27
1/4	Sch 40 (Std)	0.540	0.088	0.364	0.1041	0.425	0.0054	0.0451	18
3/8	Sch 40 (Std)	0.675	0.091	0.493	0.191	0.568	0.0099	0.0827	18
1/2	Sch 40 (Std)	0.840	0.109	0.622	0.304	0.851	0.0157	0.1316	14
3/4	Sch 40 (Std)	1.050	0.113	0.824	0.533	1.131	0.0277	0.2301	14
1	Sch 40 (Std)	1.315	0.133	1.049	0.864	1.679	0.0449	0.374	11-1/2
1-1/4	Sch 40 (Std)	1.660	0.140	1.380	1.496	2.273	0.0779	0.648	11-1/2
1/1-2	Sch 40 (Std)	1.900	0.145	1.610	2.036	2.718	0.106	0.882	11-1/2
2	Sch 40 (Std)	2.375	0.154	2.067	3.360	3.653	0.174	1.455	11-1/2
2-1/2	Sch 40 (Std)	2.875	0.203	2.469	4.079	5.793	0.249	2.076	8
3	Sch 40 (Std)	3.500	0.216	3.068	7.039	7.578	0.384	3.20	8
3-1/2	Sch 40 (Std)	4.000	0.226	3.548	9.89	9.11	0.514	4.28	8
4	Sch 40 (Std)	4.500	0.237	4.026	12.73	10.79	0.661	5.51	8
5	Sch 40 (Std)	5.563	0.258	5.047	20.01	14.62	1.04	8.66	8
6	Sch 40 (Std)	6.625	0.280	6.065	28.89	18.97	1.50	12.51	8
8	Sch 40 (Std)	8.625	0.322	7.981	50.00	28.55	2.66	21.69	8
10	Sch 40 (Std)	10.75	0.365	10.02	78.90	40.48	4.19	34.10	8
12	Standard	12.75	0.375	12.00	113.10	49.56	5.96	49.00	8
14	Standard	14.00	0.375	13.25	137.90	54.57	7.19	59.70	8

Reference Data

Physical & Thermodynamic Properties of Common Liquids

Substance	Density[1] (Lbs/Ft³)	Specific Heat (Btu/lb/°F)	Thermal Conductivity (Btu/in/hr/ft²/°F)	Melting Point (°F)	Latent Heat of Fusion (Btu/lb)	Boiling Point (°F)	Latent Heat of Vaporization (Btu/lb)	Viscosity Centipoise
Acetic Acid	65.5	0.522	1.19	62	84	245	174.2	1.222
Acetone	49.42	0.514	1.22	-140	42.1	133	224	0.31
Allyl Alcohol	53.31	0.665	1.25	-200	—	206	294.1	1.363
Ammonia	43.5	1.099	3.48	107	142.9	-28	583	—
Amyl Alcohol	51.06	0.65	1.13	-110	—	280	216.3	—
Aniline	63.77	0.512	1.2	21	48.8	364	186.6	4.467
Bromine	194.7	0.107	—	19	28.5	138	79.4	1.005
Butyl Alcohol	50.54	0.563	1.07	-130	54	244	254	2.948
Butyric Acid	60.2	0.515	1.13	20	54.1	326	217	1.54
Carbolic Acid (Phenol)	66.7	0.561	—	106	52.3	360	—	12.74
Carbon Disulfide	78.9	0.24	1.12	-169	—	115	148.8	0.376
Carbon Tetrachloride	99.47	0.201	0.744	-9	12.8	170	83.5	0.975
Caustic Soda (50% Solution)	95.4	0.78	—	—	—	—	—	—
Decane	45.6	0.5	1.03	-21	86.9	345	—	0.77
Di-ethyl Ether	44.61	0.541	—	-177	42.4	94	151	0.245
Ether	46	0.503	0.97	—	—	95	160	—
Ethyl Acetate	52.3	0.468	1.21	-116	—	171	183.8	0.45
Ethyl Alcohol	49.27	0.68	1.26	-174	46.4	173	367.5	1.2
Ethyl Bromide	90.5	0.215	—	-182	—	101	107.8	0.402
Ethyl Chloride	56.05	0.368	2.15	-214	—	54	165.9	—
Ethyl Iodide	120.8	0.161	2.57	-163	—	162	82	0.592
Ethylene Glycol	69.2	0.555	1	—	—	388	344	—
Ethylene Bromide	136.5	0.173	—	50	—	269	99.2	1.721
Ethylene Chloride	71.75	0.294	—	-35	—	183	139.2	0.838
Formic Acid	76.13	0.526	1.25	47	118.9	213	216	1.784
Glycerin	78.69	0.576	1.36	68	85.5	554	—	830
Heat Transfer Fluids								
Dowtherm A	66.1	0.377	—	54	42.2	494	127	—
Dowtherm G	65.4	0.377	—	40	42.2	551	123	—
Mobiltherm 603	53.7	0.592	—	—	—	—	—	—
Therminol VP-1	65.9	0.377	—	—	—	495	130.6	—
Heptane	42.68	0.532	0.89	-132	—	210	137.3	0.416
Hexane	41.18	0.6	0.86	-40	—	155	142.5	0.326
Linseed Oil	58.28	0.44	—	-4	—	548	—	33.1
Methyl Acetate	57.84	0.468	1.12	-144	—	134	176.6	0.388
Methyl Alcohol	49.42	0.601	1.49	-144	42.7	148	473	0.596
Methyl Iodide	142.58	—	—	-87	—	108	82.6	0.5
Nitric Acid (100%)	94.41	0.42	1.92	-42	71.5	187	270	—
Nitrobenzene	75.63	0.35	11.52	42	40.5	412	142.4	2.1
Octane	44.12	0.51	1	-70	—	258	131.7	0.542
Olive Oil	57.28	0.471	—	—	—	~ 572	—	84
Pentane	39.37	0.558	0.79	-202	—	97	153.6	0.24
Petroleum Products								
Asphalt	62.3	0.42	5.04	—	—	—	—	—
Benzene (Benzol)	54.85	0.412	1.02	42	54.2	176	169.4	0.654
Kerosene	49.9	0.5	1.03	—	—	—	—	—
Fuel Oil #6	58.5	0.41	0.85	—	—	—	—	—
Gasoline	41.2	0.5	0.936	—	—	128 - 164	—	—
Lube Oils	55.4	0.43	—	—	—	—	—	—
Paraffin (Melted)	44.3	0.71	1.68	—	—	~ 525	—	—
Toluene	54.03	0.404	1.08	-139	—	231	155.7	0.59
Propionic Acid	61.77	0.473	1.2	-5	—	286	177.8	1.102
Propyl Alcohol	50.16	0.57	—	-197	—	208	296	2.256
Soy Bean Oil	57.35	~ 0.28	—	—	—	—	—	40.6
Sulfur (Melted)	14.6	0.234	—	—	—	833	—	—
Sulfuric Acid (100%)	114.25	0.344	—	51	43.3	638	219.7	50
Tallow (Lard)	58.66	0.64	—	50 - 106	—	—	—	17.6
Turpentine	54.48	0.42	0.876	14	—	319	123.5	1.487
Water	**62.4**	**1**	**4.17**	**32**	**143.6**	**212**	**972**	**1.005**
Xylene (Ortho)	55	0.411	1.08	-13	—	291	149.2	0.881

1. Where the temperature is not given, room temperature of 68°F (20°C) is understood.

Other Notes —
A. Dowtherm is a trademark of the Dow Chemical Company.
B. Mobiltherm is a trademark of the Mobil Oil Corporation.
C. Therminol is a trademark of the Monsanto Company.

Reference Data

Properties of Air

Specific Heat, Viscosity & Density (Weight) of Air at Various Pressures & Temperatures

Air Temp (°F)	Specific Heat (Btu/ Lbs/°F)	Absolute Viscosity (Lbs/ Ft/Hr)	Gauge Pressure in Lbs/In^2 (based on atmospheric pressure of 14.7 Lbs/In^2 absolute at sea level)														
			0	10	20	30	40	50	60	70	80	100	120	150	200	250	300
			Density (Weight) in Lbs/Ft^3														
-20	0.239	0.039	0.0900	0.152	0.213	0.274	0.336	0.397	0.458	0.519	0.580	0.702	0.825	1.010	1.318	1.625	1.934
-10	0.239	0.039	0.0882	0.149	0.209	0.268	0.328	0.388	0.448	0.508	0.567	0.687	0.807	0.989	1.288	1.588	1.890
0	0.239	0.040	0.0864	0.146	0.204	0.263	0.322	0.380	0.438	0.497	0.556	0.672	0.790	0.968	1.260	1.553	1.850
10	0.239	0.040	0.0846	0.143	0.199	0.257	0.315	0.372	0.429	0.486	0.543	0.658	0.774	0.947	1.233	1.520	1.810
20	0.239	0.041	0.0828	0.140	0.196	0.252	0.307	0.365	0.421	0.477	0.533	0.645	0.757	0.927	1.208	1.489	1.770
30	0.240	0.041	0.0811	0.137	0.192	0.247	0.302	0.357	0.412	0.467	0.522	0.632	0.742	0.908	1.184	1.460	1.730
40	0.240	0.042	0.0795	0.134	0.188	0.242	0.295	0.350	0.404	0.458	0.511	0.619	0.727	0.890	1.161	1.431	1.705
50	0.240	0.042	0.0780	0.131	0.184	0.237	0.291	0.343	0.396	0.449	0.501	0.607	0.713	0.873	1.139	1.403	1.661
60	0.240	0.043	0.0764	0.128	0.180	0.232	0.284	0.336	0.388	0.440	0.493	0.596	0.700	0.856	1.116	1.376	1.638
70	0.240	0.044	0.0750	0.126	0.177	0.228	0.279	0.330	0.381	0.432	0.482	0.584	0.686	0.839	1.095	1.350	1.604
80	0.240	0.045	0.0736	0.124	0.174	0.224	0.274	0.324	0.374	0.423	0.473	0.572	0.673	0.824	1.074	1.325	1.573
90	0.240	0.045	0.0723	0.122	0.171	0.220	0.269	0.318	0.367	0.415	0.464	0.561	0.660	0.809	1.054	1.300	1.546
100	0.240	0.046	0.0710	0.120	0.168	0.215	0.264	0.312	0.360	0.408	0.455	0.551	0.648	0.794	1.035	1.276	1.517
120	0.240	0.047	0.0686	0.116	0.162	0.208	0.255	0.302	0.348	0.394	0.440	0.533	0.626	0.767	1.001	1.234	1.465
150	0.241	0.049	0.0652	0.110	0.154	0.199	0.243	0.287	0.331	0.375	0.419	0.508	0.596	0.730	0.953	1.175	1.392
175	0.241	0.051	0.0626	0.105	0.148	0.191	0.234	0.275	0.318	0.361	0.403	0.488	0.573	0.701	0.914	1.128	1.337
200	0.241	0.052	0.0603	0.101	0.143	0.184	0.225	0.266	0.305	0.347	0.388	0.470	0.552	0.674	0.879	1.084	1.287
250	0.242	0.055	0.0560	0.094	0.132	0.171	0.208	0.247	0.285	0.322	0.360	0.436	0.513	0.627	0.817	1.007	1.197
300	0.243	0.058	0.0523	0.088	0.124	0.159	0.195	0.230	0.265	0.301	0.336	0.407	0.478	0.585	0.762	0.940	1.118
350	0.244	0.060	0.0491	0.083	0.116	0.150	0.184	0.216	0.249	0.282	0.316	0.382	0.449	0.549	0.715	0.883	1.048
400	0.245	0.063	0.0463	0.078	0.109	0.140	0.172	0.203	0.235	0.266	0.298	0.360	0.423	0.517	0.674	0.831	0.987
500	0.248	0.067	0.0414	0.067	0.098	0.126	0.154	0.182	0.210	0.238	0.266	0.322	0.379	0.463	0.604	0.746	0.885
600	0.25	0.072	0.0376	0.063	0.089	0.114	0.140	0.165	0.190	0.216	0.241	0.292	0.343	0.419	0.547	0.675	0.801
700	0.254	0.076	0.0341	0.058	0.081	0.104	0.127	0.151	0.174	0.198	0.221	0.267	0.328	0.383	0.500	0.616	0.733
800	0.257	0.080	0.0314	0.053	0.071	0.096	0.117	0.139	0.160	0.181	0.203	0.246	0.314	0.353	0.460	0.568	0.675
900	0.259	0.085	0.0295	0.049	0.069	0.089	0.109	0.129	0.148	0.168	0.188	0.228	0.289	0.327	0.427	0.526	0.625
1000	0.262	0.089	0.0275	0.046	0.064	0.083	0.101	0.120	0.138	0.157	0.175	0.212	0.268	0.304	0.397	0.490	0.582

Calculation of Density at Other Temperatures & Pressures

Density at a specific pressure and temperature can be converted to density at another pressure and temperature using the following equation:

$$D_2 = D_1 \frac{T_1}{T_2} \times \frac{P_2}{P_1}$$

Where:

T_1 = (°F + 460°) initial condition
T_2 = (°F + 460°) new condition
D_1 = density lbs/ft^3 initial condition
D_2 = density lbs/ft^3 new condition
P_1 = absolute pressure (psia) initial condition
P_2 = absolute pressure (psia) new condition

Calculation of Flow or Volume

The same formula can be used to convert air flow or volume at gauge pressure (psig) to standard conditions (atmospheric pressure at 70°F) by substituting cubic feet (ft^3) or cubic feet per minute (CFM) for density (D):

$$\text{Std. CFM} = \text{Actual CFM} \frac{(70 + 460)}{(T_2 + 460)} \times \frac{(\text{psig} + 14.7)}{14.7 \text{ psia}}$$

Water Vapor Content of Air in Pounds of Water/100 Ft^3 at Various Temperatures & Relative Humidity

Air (°F)	Lbs/100 Ft^3 at Specified Relative Humidity																
	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
-20	.001	.001	.001	.001	.001	.002	.002	.002	.002	.002	.002	.002	.003	.003	.003	.003	.003
-10	.001	.001	.001	.001	.002	.002	.002	.002	.003	.003	.003	.003	.003	.003	.004	.004	.004
0	.001	.002	.002	.002	.003	.003	.004	.004	.004	.005	.005	.005	.006	.006	.006	.007	.007
10	.002	.003	.003	.004	.004	.005	.006	.006	.007	.007	.008	.008	.009	.009	.010	.010	.011
20	.004	.005	.005	.006	.007	.008	.009	.010	.011	.012	.013	.014	.014	.015	.016	.017	.018
30	.006	.007	.008	.010	.011	.013	.014	.015	.017	.018	.020	.021	.022	.024	.025	.027	.028
40	.008	.010	.012	.014	.016	.018	.021	.023	.025	.027	.029	.031	.033	.035	.037	.039	.041
50	.012	.015	.018	.021	.024	.027	.030	.032	.035	.038	.041	.044	.047	.050	.053	.056	.059
60	.017	.021	.025	.029	.033	.037	.042	.046	.050	.054	.058	.062	.066	.071	.075	.079	.083
65	.020	.025	.029	.034	.039	.044	.049	.054	.059	.064	.069	.074	.078	.083	.088	.093	.098
68	.022	.027	.032	.038	.043	.049	.054	.059	.065	.070	.076	.081	.086	.092	.097	.103	.108
70	.023	.029	.035	.040	.046	.052	.058	.063	.069	.075	.081	.086	.092	.098	.104	.109	.115
71	.024	.030	.036	.042	.048	.054	.060	.065	.071	.077	.083	.089	.095	.101	.107	.113	.119
72	.025	.031	.037	.043	.049	.055	.062	.068	.074	.080	.086	.092	.098	.105	.111	.117	.123
73	.025	.032	.038	.044	.051	.057	.064	.070	.076	.083	.089	.095	.102	.108	.114	.121	.127
74	.026	.033	.039	.046	.052	.059	.066	.072	.079	.085	.092	.098	.105	.111	.118	.124	.131
75	.027	.034	.041	.047	.054	.061	.068	.074	.081	.088	.094	.101	.108	.115	.122	.128	.135
78	.030	.037	.044	.052	.059	.067	.074	.081	.089	.096	.104	.111	.118	.126	.133	.141	.148
80	.032	.040	.047	.055	.063	.071	.079	.087	.095	.103	.111	.119	.126	.134	.142	.150	.158
85	.037	.046	.055	.064	.074	.083	.092	.101	.110	.120	.129	.138	.147	.156	.166	.175	.184
90	.043	.053	.064	.075	.085	.096	.107	.117	.128	.138	.149	.160	.170	.181	.192	.202	.213
95	.049	.062	.074	.086	.099	.111	.124	.136	.148	.161	.173	.185	.198	.210	.222	.225	.247
100	.057	.071	.036	.100	.114	.128	.143	.157	.171	.185	.200	.214	.228	.242	.257	.271	.285

Note — To convert “grains of moisture” to pounds, multiply grains by 0.0001428.

Reference Data

Physical & Thermodynamic Properties of Common Gases

Properties of Common Gases at Normal Temperatures

Substance	Density[1] (Lbs/Ft³)	Specific Ht. at Constant Press[2] (Btu/lb/°F)	Thermal Conductivity (Btu/in/hr/ft²/°F)	Melting Point (°F)	Latent Heat Fusion[2] (Btu/lb³)	Boiling Point (°F)	Latent Heat Vaporization (Btu/lb)
Acetylene	0.068	0.3832	0.129	-114.34	—	-118.48	—
Air	0.0748	0.2400	0.18	—	—	—	92
Ammonia	0.048	0.5202	0.154	-103	194.4	-28.3	589
Argon	0.1033	0.1233	0.113	-308.56	12.1	-302.26	67.9
Butane-iso	0.16	—	0.0948	-229	—	13.64	157.3
Butane-n	0.15	—	0.0876	-211	—	33.08	164.7
Carbon Dioxide	0.1144	0.2025	0.12	-109.3	81.5	Sublimates	245
Carbon Monoxide	0.0725	0.2425	0.18	-340.6	14.4	-312.7	90.7
Chlorine	0.1853	0.1125	0.058	-150.88	44.4	-30.46	145.8
Chlorodifluoromethane (F-22)	0.289	0.1510	—	-256	—	-41.36	—
Chloroform	—	0.1440	0.0972	—	—	143.1	—
Cyanogen	0.14	0.4095	—	-18.22	—	-6.106	—
Dichlorodifluoromethane (F-12)	0.329	0.1410	0.058	-252	—	-21.62	—
Ethane	0.084	0.3861	0.13	-277.6	—	-126.94	464.4
Ethyl Chloride	0.179	0.2750	0.0610	-217.7	—	53.96	166.5
Ethylene	0.078	0.3990	0.1230	-272.92	—	-154.84	—
Fluorine	0.1059	0.1820	0.1760	-369.4	—	-304.6	72.9
Helium	0.0103	1.2500	0.9880	-457.6	—	-452.092	10.7
Hydrogen	0.0056	3.4090	1.16	-434.45	25.2	-423.755	192
Hydrogen Bromide	0.2275	0.0820	—	-124.06	13.8	-91.66	87.7
Hydrogen Chloride	0.1023	0.1940	0.0910	-168.34	24.1	-117.58	190.6
Hydrogen Fluoride	0.0535	—	—	-134.14	—	-34.06	0.3
Hydrogen Iodide	0.355	0.0600	—	-60.34	10.2	-32.26	61
Hydrogen Sulfide	0.096	0.2451	0.091	-122.8	—	-79.6	237.4
Methane	0.0446	0.5929	0.214	-296.5	26.2	-258.52	248.4
Methyl Chloride	0.142	0.2400	0.0648	-154.48	—	-10.714	184.1
Methyl Ether	0.131	—	—	-216.4	—	-12.82	—
Methyl Fluoride	0.096	—	—	—	—	-108.4	—
Neon	0.056	—	0.322	-415.61	5.1	-410.62	—
Nitric Oxide	0.0777	0.2320	0.1656	-268.6	33.1	-243.4	—
Nitrogen	0.073	0.2438	0.186	-345.75	11	-320.44	86
Nitrous Oxide	0.123	0.2126	0.1056	-152.32	—	-129.64	—
Oxygen	0.083	0.2175	0.18	-361.12	6	-297.4	91.8
Phosphine	0.095	—	—	-208.3	—	-125.32	—
Propane	0.126	—	0.097	-309.82	—	-48.1	—
Silicone Tetrafluoride	0.292	—	—	—	—	-90.4	—
Sulfur Dioxide	0.166	0.1544	0.07	-104.8	—	14	170.6
Water Vapor	0.0372	0.4820	0.1700	32	143.6	212	972
Xenon	0.365	—	—	-220	6.71	-164.38	43.9

1. Weight in lbs/ft³ at approximately 70°F and atmospheric pressure.
2. Where temperature is not given, 68°F (20°C) is understood.
3. All properties are at a pressure equivalent to 760 mm of mercury, unless otherwise indicated.

Properties of Common Gases at Cryogenic Temperatures

Properties / Gases	N_2	O_2	He	H_2	CH_4	NH_3	A	Ne
Density @ 32°F Atm lb/ft³	0.0781	0.0892	0.01114	0.00561	0.0448	0.0481	0.1113	0.0562
Boiling Point @ 1 Atm - °F	-320.4	-297.4	-452	-423	-258.7	-28.03	-302.4	-410.6
Melting Point @ 1 Atm - °F	-345.8	-361.1	-458 (26 Atm)	-434.6	-299.2	-107.9	-308.7	-415.7
Vapor Density @ BP - lbs/ft³	0.288	0.296	0.999	0.083	0.1124	0.0556	0.368	0.593
Liquid Density @ BP - lbs/ft³	50.19	71.29	7.803	4.37	26.47	42.58	86.77	74.91
Vapor Pressure Solid @ MP in mm.	96.4	2.0	< .02	54	70.0	45.2	516	323
Heat of Vapor @ BP - Btu/lb	85.7	91.6	< .03	194.4	248.4	588.6	70.0	37.4
Heat of Fusion @ MP - Btu/lb	11.0	5.9	< 1.8	25.2	26.1	151.2	12.1	7.2
Cp @ 50°F @ 1 Atm - Btu/lb°F	0.248	0.218	1.25 (-292°F)	3.39	0.528	0.523	0.125	0.25 (Approx)
Cp/Cv @ 59 - 68°F @ 1 Atm	1.40	1.40	1.65 (292°F)	1.41	1.31	1.31	1.67	1.64
Critical Temperature - °F	-232.8	-181.1	-450.2	-399.8	-116.5	270.3	-188.5	-379.7
Critical Pressure @ 1 Atm	33.5	50.1	2.26	12.8	45.8	111.5	48.0	26.8

Reference Data

Physical & Thermodynamic Properties of Common Solids

Properties of Metals (Solid)

Substance	Density (Lb/Ft^3)	Specific Heat (Btu/lb/°F)	Thermal Conductivity (Btu/ in/hr/ft^2/°F)	Melting Point (°F)	Latent Heat Fusion (Btu/lb)
Aluminum	169	0.226	1536	1220	167.4
Antimony	413	0.0504	127	1167	70.2
Babbitt - Tin	462	0.071	278	465	279
Barium	218	0.068	—	1562	—
Beryllium	113	0.425	960	2462	572.4
Bismuth	610	0.0294	62	520	22.5
Brass (Yellow)	529	0.092	768	~ 1680	—
Cadmium	540	0.0552	644	609	23
Calcium	97	0.168	910	1490	140
Carbon	165	0.165	165	> 6400	—
Chromium	432	0.111	480	2940	126
Cobalt	544	0.1001	336	2696	115.2
Copper	555	0.0928	2784	1981	88.7
Gold	1204	0.0312	2352	1945	28.6
INCOLOY® 800	495	0.108	80	2475	—
INCONEL® 600	525	0.106	103	2470	—
Iridium	1399	0.0323	448	4449	47
Iron (99.97%)	491	0.1075	498	2795	117
Lead	708	0.0306	243	621	10.8
Lithium	33	0.79	516	357	217
Magnesium	108	0.246	1188	1204	126
Manganese	449	0.1211	81	2300	116
Mercury	845	0.0333	58	-38	4.98
Molybdenum	636	0.065	948	4748	126
MONEL® 400	551	0.11	144	2370	—
Nickel	552	0.1032	432	2624	131.4
Platinum	1333	0.0319	492	3224	48.4
Potassium	54	0.177	720	146	26.3
Rhodium	776	0.058	666	3570	—
Silver	665	0.0557	2904	1761	46.6
Sodium	60	0.283	970	208	48.6
Solder 50%Sn - 50%Pb	550	0.04	340	~ 440	17
Steel, Carbon	487	0.12	315	2548	—
Steel, SS	501	0.12	113	2550	—
Tantalum	1035	0.036	384	5162	—
Tin	454	0.0548	432	449	25.9
Titanium	281	0.1125	108	3272	—
Type Metal 85%Pb - 15%Sb	625	0.04	180	~ 479	14
Tungsten	1204	0.032	1104	6119	79
Uranium	397	0.028	168	< 3362	—
Vanadium	349	0.1153	240	3110	—
Zinc	445	0.0931	780	787	47.9
Zirconium	408	0.066	132	3452	108

Note — Where temperature is not given, 68°F (20°C) temperature is understood.

Properties of Metals (Liquid)

Metal	Melting Point (°F)	Latent Ht. of Fusion (Btu/lb)	Liquid Temp. (°F)	Density (Lbs/ft^3)	Specific Heat (Btu/ Lb/°F)	Thermal Conductivity (Btu/ in/hr/ft^2/°F)
Aluminum	1220	173	1220	148.6	0.26	—
	—	—	1292	147.7	0.26	717
	—	—	1454	—	0.26	842
Bismuth	520	21.6	600	625	0.034	114
	—	—	1000	608	0.037	108
	—	—	1400	591	0.039	108
Cadmium	609	23.8	626	500	0.063	—
	—	—	660	499	0.063	308
	—	—	752	495	0.063	—
Gold	1945	26.9	2012	1,076	0.036	—
Lead	621	10.6	700	658	0.038	126
	—	—	900	650	0.037	137
	—	—	1300	633	—	—
Lithium	357	284	392	31.7	1	262
	—	—	752	31	1	—
Magnesium	1204	148	1204	98	0.317	—
	—	—	1328	94	—	—
	—	—	1341	—	0.321	—
Mercury	-38	5	50	847	0.033	56
	—	—	300	826	0.033	80
	—	—	600	802	0.032	97
Potassium	146	26.3	300	50.4	0.190	312
	—	—	800	46.3	0.183	274
	—	—	1300	42.1	0.180	229
Silver	1761	44.8	1761	581	0.069	—
	—	—	1832	578	0.069	—
	—	—	2000	574	0.069	—
Sodium	208	48.7	200	58	0.33	598
	—	—	400	56	0.32	557
	—	—	700	54	0.31	502
	—	—	1300	49	0.30	414
Solder						
50%Sn - 50%	421	17	—	—	0.056	—
60%Sn - 40%	375	28	—	—	0.058	—
Tin	449	26.1	482	—	0.058	—
	—	—	768	427	—	—
	—	—	783	—	—	229
Zinc	787	43.9	787	432	0.12	—
	—	—	932	—	—	400
	—	—	1112	425	0.117	394

Reference Data

Physical & Thermodynamic Properties of Common Solids

Properties of Non-Metallic Solids

Substance	Density (Lbs/Ft³)	Specific Heat (Btu/lb/°F 20°C 68°F)	Thermal Conductivity (Btu/in/hr/ft²/°F)	Melting Point (°F)
Alumina	231	0.19	205	—
Aluminum Silicate (Lava)	130	0.25	9	—
Asphalt	81	0.4	5.2	250
Bakelite	81	0.35	116	—
Basalt	184	0.2	—	—
Beeswax	60	—	—	144
Boron Nitride (Comp.)	130	0.32	150	—
Brick, Building	123	0.22	4.8	—
Carbon, Powder	131	0.168	2.4	6400
Graphite, Solid	140	0.165	1044	—
Graphite, Powder	130	0.165	1.27	—
Diamond	219	0.16	15840	—
Cellulose (Pulp)	3.4	0.35	0.32	—
Chalk	143	0.215	5.76	—
Charcoal (Oak)	33	0.2	0.36	—
Clay	115	0.22	9	—
Coal (Anthracite)	97	0.3	1.18	—
Coke	75	0.36	6.6	—
Concrete, Sand	144	0.22	12.6	—
Concrete, Cinder	97	0.21	4.92	—
Cordierite	138	0.35	23	—
Cork (Granulated)	5.4	0.485	0.336	—
Earth (42% H_2O)	108	0.9	7.44	—
Earth (Dry, Packed)	95	0.42	0.9	—
Earth (Dry, Stony)	127	0.44	3.6	—
Fiberglas® (Insul.)	0.75	—	0.29	—
Fiberglas® (Insul.)	3	—	0.22	—
Firebrick (Clay)	112	0.198	6.96	—
Fosterite	174	0.23	26	—
Fused Silica (Quartz)	137	0.31	9.96	—
Glass				
Normal	139	0.199	7.08	2200
Crown	154	0.161	7.08	—
Flint (Leaded)	200	0.117	9.48	—
Pyrex	139	0.20	7.08	—
Granite	159	0.192	13 - 28	—
Ice -0°C (32°F)	57.5	0.465	15.6	32
Limestone	153	0.217	6.48	—

Properties of Non-Metallic Solids

Substance	Density (Lbs/Ft³)	Specific Heat (Btu/lb/°F 20°C 68°F)	Thermal Conductivity (Btu/in/hr/ft²/°F)	Melting Point (°F)
Magnesia 85% (Insul.)	12	0.222	4.2	—
Magnesium Oxide	135	0.25	17.6	—
Marble	170	0.21	18	—
Mica	165	0.206	3	—
Paper	58	0.32	0.9	—
Plastics				
ABS	62.2	0.3 - 0.4	1.56	—
Cellulose Acetate	82.9	0.3 - 0.42	2.28	—
Epoxy (Resin)	71.8	0.4 - 0.5	1.2 - 3.5	—
Fluoroplastic (PTFE)	133	0.25	1.68	—
Nylon	69.1	0.4	1.2	—
Phenolic	82.9	0.35	0.097 - 0.3	—
Polyethylene	57	0.55	2.28	—
Polystyrene	64.8	0.32	0.7 - 1.08	—
Polystyrene (Exp.)	1.7	0.29	0.252	—
Polypropylene	56.7	0.45	1.21 - 1.36	—
Polyurethane (Exp.)	1.5	0.38	0.228	—
Polyvinyl	86.4	0.2 - 0.3	0.84 - 1.20	—
Paraffin	56	0.69	1.68	133
Porcelain	145	0.26	15.6	—
Pyroceram	163	0.233	23.4	—
Quartz	138	0.17	27.6	3150
Rigid Insulation				
Fiber Board	14.8	0.21	0.28	1472
Inorganic Bonded	10 - 15		0.45	
Rock Salt	136		—	
Rubber Soft	68.6	0.48	0.96	—
Rubber, Hard	74.3	0.48	1.104	—
Sand	94	0.195	2.25	—
Silicon	145	0.181	—	2577
Sodium Carbonate	135	0.30	—	1546
Sodium Chloride	135	0.22	—	1440
Sodium Cyanide	94	0.3	—	1015
Sodium Nitrate	141	0.29	—	555
Sodium Nitrite	135	0.3	—	490
Steatite	158	0.2	23.2	—
Sugar	105	0.3	—	160
Sulfur	129	0.181	1.8	—
Woods (Average)	23 - 70	0.45 - 0.67	0.78 - 1.78	—
Oak, Red	42	0.57	1.188	—
Pine, White	25	0.67	0.72	—

Reference Data

Equivalents & Conversions

Temperature Equivalents (°F and °C)

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
-50	-58	95	203	240	464	385	725	530	986	675	1247	820	1508	965	1769
-45	-49	100	212	245	473	390	734	535	995	680	1256	825	1517	970	1778
-40	-40	105	221	250	482	395	743	540	1004	685	1265	830	1526	975	1787
-35	-31	110	230	255	491	400	752	545	1013	690	1274	835	1535	980	1796
-30	-22	115	239	260	500	405	761	550	1022	695	1283	840	1544	985	1805
-25	-13	120	248	265	509	410	770	555	1031	700	1292	845	1553	990	1814
-20	-4	125	257	270	518	415	779	560	1040	705	1301	850	1562	995	1823
-15	-5	130	266	275	527	420	788	565	1049	710	1310	855	1571	1000	1832
-10	14	135	275	280	536	425	797	570	1058	715	1319	860	1580	1005	1841
-5	23	140	284	285	545	430	806	575	1067	720	1328	865	1589	1010	1850
0	32	145	293	290	554	435	815	580	1076	725	1337	870	1598	1015	1859
5	41	150	302	295	563	440	824	585	1085	730	1346	875	1607	1020	1868
10	50	155	311	300	572	445	833	590	1094	735	1355	880	1616	1025	1877
15	59	160	320	305	581	450	842	595	1103	740	1364	885	1625	1030	1886
20	68	165	329	310	590	455	851	600	1112	745	1373	890	1634	1035	1895
25	77	170	338	315	599	460	860	605	1121	750	1382	895	1643	1040	1904
30	86	175	347	320	608	465	869	610	1130	755	1391	900	1652	1045	1913
35	95	180	356	325	617	470	878	615	1139	760	1400	905	1661	1050	1922
40	104	185	365	330	626	475	887	620	1148	765	1409	910	1670	1055	1931
45	113	190	374	335	635	480	896	625	1157	770	1418	915	1679	1060	1940
50	122	195	383	340	644	485	905	630	1166	775	1427	920	1688	1065	1949
55	131	200	392	345	653	490	914	635	1175	780	1436	925	1697	1070	1958
60	140	205	401	350	662	495	923	640	1184	785	1445	930	1706	1075	1967
65	149	210	410	355	671	500	932	645	1193	790	1454	935	1715	1080	1976
70	158	215	419	360	680	505	941	650	1202	795	1463	940	1724	1085	1985
75	167	220	428	365	689	510	950	655	1211	800	1472	945	1733	1090	1994
80	176	225	437	370	698	515	959	660	1220	805	1481	950	1742	1095	2003
85	185	230	446	375	707	520	968	665	1229	810	1490	955	1751	1100	2012
90	194	235	455	380	716	525	977	670	1238	815	1499	960	1760	1105	2021

Values for Interpolation in Above Table

1°C = 1.8°F
2°C = 3.6°F
3°C = 5.4°F
4°C = 7.2°F
5°C = 9°F
6°C = 10.8°F
7°C = 12.6°F
8°C = 14.4°F
9°C = 16.2°F
1°F = 0.55°C
2°F = 1.11°C
3°F = 1.66°C
4°F = 2.22°C
5°F = 2.77°C
6°F = 3.33°C
7°F = 3.88°C
8°F = 4.44°C
9°F = 5°C

Note — All decimals are exact. All decimals are repeating decimals.

Formula for Converting Temperature Scales

Fahrenheit to Celsius	°F = 1.8°C + 32
Celsius to Fahrenheit	°C = 5/9 x (°F - 32)
Fahrenheit to Rankine (absolute)	°R = °F + 460
Celsius to Kelvin (absolute)	°K = °C + 273

Pressure Equivalents

Unit	Lbs/In^2	Kg/cm^2	Atm	Bar	Pascals	mm Hg. (0°C)	In. Hg (32°F)	Ft H$_2$0 (60°F)
1 lbs/in^2	1	0.0703	0.06804	0.06895	6,895	51.715	2.036	2.3086
1 kg/cm.^{2}	14.22	1	0.9678	0.98066	98,066	735.56	28.96	32.843
1 Atmosphere (atm)	14.696	1.0333	1	1.01325	101,326	760	29.921	33.925
1 Bar	14.504	1.019716	0.9869	1	1 x 10^5	750.06	29.53	33.49
1 Pascal (N/m^2)	14.5 x 10^{-5}	1.03 x 10^{-5}	1 x 10^{-5}	1 x 10^{-5}	1	7.5 x 10^5	0.000295	0.000335
1 mm Hg. (0°C)	0.01934	1.35951	0.1316	0.1333	13,330	1	0.03937	0.04465
1 in. Hg. (32°F)	0.4912	0.034532	0.03342	0.03386	3,386	25.4	1	1.1342
1 ft. H$_2$0 (60°F)	0.4331	0.03045	0.02947	0.02986	2,987	22.396	0.88175	1
100 ft H$_2$0 (60°F)	43.31	3.0448	2.9469	2.9859	298,700	2239.6	88.175	100

Notes —
A. 1 inch of Hg (Mercury) = 13.6 inches of water.
B. 1 pound per square inch (psi) = 2.31 feet of water.
C. 1 foot of water = 0.4331 pounds per square inch (psi).

Reference Data

Engineering Constants & Conversions

Common Conversion Factors

To Convert	Units	Multiply By	To Obtain	Units
Atmospheres	atm	1.0133	Bar	
Atmospheres	atm	29.92	Inches Mercury	in. Hg
Bar		0.9869	Atmospheres	atm
Bar		14.504	Pounds/square inch	psi
British thermal unit	Btu	1,055	Joules	J
British thermal unit	Btu	0.0002931	Kilowatts	kW
British thermal unit	Btu	0.2931	Watts	W
British thermal unit	Btu	0.252	Kilocalories	kcal
Brit. ther. units/hr	Btuh	0.2931	Joules/second	J/s
Brit. ther. units/hr	Btuh	0.2931	Watt/hours	Wh
Brit. ther. units/hr	Btuh	0.0002931	Kilowatt/hours	kWh
Brit. ther. units inch/hour/sqft/°F	Btu/in/h ft^2/°F	0.1442	Watts/meter/°C	W/m/°C
Calories	cal	4.187	Joules	J
Centimeter	cm	0.03281	Feet	ft
Centimeter	cm	0.3937	Inches	in.
Centimeters/second	cm/s	1.969	Feet/minute	fpm
Cubic centimeter	cm^3	0.061	Cubic inches	in^3
Cubic feet	ft^3	62.43	Pounds of water	lb
Cubic feet	ft^3	28.32	Cubic centimeters	cm^3
Cubic feet	ft^3	0.02832	Cubic meters	m^3
Cubic feet	ft^3	7.481	Gallons, U.S.	gal
Cubic feet	ft^3	28.32	Liters	l
Cubic feet/minute	cfm	1.699	Cubic meters/hour	m^3/h
Cubic feet/minute	term	0.000472	Cubic meters/sec	m^3/s
Cubic feet/minute	cfm	0.4719	Liters/second	l/s
Cubic inch	in^3	16.39	Cubic centimeters	cm^3
Cubic meter	m^3	35.32	Cubic feet	ft^3
Cubic meter	m^3	264.2	Gallons, U.S.	gal
Cubic meter	m^3	1,000	Liters	l
Cubic meters/hr	m^3/h	0.5885	Cubic feet/min.	cfm
Cubic meters/hr	m^3/h	4.403	Gallons/min.	gpm
Cubic meters/sec	m^3/s	2,119	Cubic feet/min.	cfm
Feet	ft	30.48	Centimeters	cm
Feet	ft	0.3048	Meters	m
Feet/minute	fpm	0.508	Centimeters/sec.	cm/s
Feet/minute	fpm	0.00508	Meters/sec.	m/s
Gallon, Imperial		1.201	Gallons, U.S.	gal
Gallon, U.S.	gal	231	Cubic inches	in^3
Gallon, U.S.	gal	0.1337	Cubic feet	ft^3
Gallon, U.S.	gal	8.337	Pounds of water	lb
Gallon, U.S.	gal	0.8327	Gallon Imperial	
Gallon, U.S.	gal	3.785	Liters	l
Gallon, U.S.	gal	0.003785	Cubic meters	m^3
Gallons/minute	gpm	0.2271	Cubic meters/hr	m^3/h
Gallons/minute	gpm	0.06309	Liters/sec.	l/s
Grams	g	0.035274	Ounces	oz
Grams	g	0.002205	Pounds	lb
Grams/cu centimeter	g/cm^3	1,000	Kilograms/cu meter	kg/m^3
Grams/cu centimeter	g/cm^3	62.43	Pounds/cubic foot	lb/ft^3
Grams/cu centimeter	g/cm^3	0.03613	Pounds/cubic inch	lb/in^3
Horsepower	hp	0.7457	Kilowatts	kW
Horsepower	hp	2,545	British thermal units	Btu
Horsepower	hp	33,000	Foot-lbs/min	ft-lb/min
Horsepower, boiler	bhp	9.803	Kilowatts	kW
Horsepower, boiler	bhp	3,352	British ther. units/hr	Btuh
Inches	in.	2.54	Centimeters	cm
Inches	in.	25.4	Millimeters	mm
Inches Mercury	in. Hg	0.03342	Atmospheres	atm
Inches Mercury	in. Hg	0.03937	Torr	

Common Conversion Factors

To Convert	Units	Multiply By	To Obtain	Units
Joules	J	0.000948	British thermal unit	Btu
Joules	J	0.2388	Calories	cal
Joules	J	0.0002778	Watt/hrs	Wh
Joules/second	J/s	1	Watts	W
Kilocalories/hour	kcal/h	3.969	British ther. units/hr	Btuh
Kilograms	kg	2.205	Pounds	lb
Kilo./cubic meter	kg/m^3	0.001	Grams/cu centimeter	g/cm^3
Kilo./cubic meter	kg/m^3	0.06243	Pounds/cubic foot	lb/ft^3
Kilograms/sq cm	kg/cm^2	14.22	Pounds/square inch	psi
Kilojoule	kJ	0.2778	Watt/hrs	Wh
Kilometers/hour	km/h	0.6315	Miles/hr	mph
Kilopascal	kPa	0.145	Pounds/square inch	psi
Kilowatt/hours	kWh	3,412	British ther. units/hr	Btuh
Kilowatt	kW	3,412	British thermal units	Btu
Liter	l	0.03532	Cubic feet	ft^3
Liter	l	0.001	Cubic meters	m^3
Liter	l	0.2642	Gallon, U.S.	gal
Liters/second	l/s	2.119	Cubic feet/min.	cfm
Liters/second	l/s	15.85	Gallons/min.	gpm
Meter	m	3.281	Feet	ft
Meter	m	39.37	Inches	in.
Meters/second	m/s	196.9	Feet/min.	fpm
Miles/hour	mph	1.609	Kilometers/hr	km/h
Milliliter	ml	1	Cubic centimeters	cm^3
Millimeter	mm	0.03937	Inches	in.
Newtons/sq meter	N/m^2	0.000145	Pounds/square inch	psi
Ounce	oz	28.35	Grams	g
Pound	lb	453.6	Grams	g
Pound	lb	0.4536	Kilograms	kg
Pounds/cubic foot	lb/ft^3	0.01602	Grams/cu centimeter	g/cm^3
Pounds/cubic foot	lb/ft^3	16.02	Kilograms/cu meter	kg/m^3
Pounds/cubic inch	lb/in^3	27.68	Grams/cu centimeter	g/cm^3
Pounds/square inch	psi	0.06805	Atmospheres	atm
Pounds/square inch	psi	0.06895	Bar	
Pounds/square inch	psi	0.07031	Kilograms/sq cm	kg/cm^2
Pounds/square inch	psi	6.895	Kilopascals	kPa
Pounds/square inch	psi	6.895	Newtons/sq meter	N/m^2
Pounds/square inch	psi	51.71	Torr	
Square centimeters	cm^2	0.001076	Square feet	ft^2
Square centimeters	cm^2	0.155	Square inches	in^2
Square feet	ft^2	929	Square centimeters	cm^2
Square feet	ft^2	0.0929	Square meters	m^2
Square inches	in^2	6.452	Square centimeters	cm^2
Square meters	m^2	10.76	Square feet	ft^2
Torr		0.001316	Atmospheres	atm
Torr		25.4	Inches Mercury	in. Hg
Watt-hours	Wh	3,600	Joules	J
Watt-hours	Wh	3.412	British ther. units/hr	Btuh
Watt-hours	Wh	3.6	Kilojoules	kJ
Watt-hours	Wh	0.001	Kilowatt-hours	kWh
Watts	W	1	Joules/second	J/s
Watts	W	3.412	British thermal units	Btu
Watts	W	0.001	Kilowatts	kW
Watts/meter/°C	W/m/°C	6.934	British ther. units inch/hour/ sqft/°F	Btu/in./hr/ft^2/°F
Watts/sq centimeter	W/cm^2	6.452	Watts/square inch	W/in^2
Watts/square inch	W/in^2	0.155	Watts/sq centimeter	W/cm^2
Yards	yd	0.944	Meters	m

TECHNICAL INFORMATION

Reference Data

Corrosion Guide for Electric Immersion Heaters

Corrosion Guide

The Corrosion Guide on the following pages provides suggested sheath materials for many applications. While it is by no means complete, the guide does include all of the readily available sheath materials and a wide variety of common chemicals and solutions. The compilation is based on available data and application experience and is furnished as a guide to the user. The recommendations are only suggestions and should not be interpreted as an absolute choice of sheath material in a particular application.

Types of Corrosion

In immersion heater applications, a protective or “passive” film forms on the surface of a metal sheath which protects it from further corrosion. As long as the film remains intact, the base metal is protected. Corrosion mechanisms destroy the protective film and allow the base metal to be attacked. Sheath corrosion takes a number of different forms. The most common are:

- General Corrosion
- Galvanic Corrosion
- Stress Corrosion Cracking
- Intergranular Corrosion.

Temperature accelerates the corrosion process. Austenitic stainless steels are particularly susceptible to stress corrosion cracking and intergranular corrosion.

Sheath Selection Process

Since it is the responsibility of the end user to make the final selection of sheath material for any particular application, the information in this guide may be used as a reference in the investigation of a particular process. Select the sheath material and watt density based upon your intimate knowledge of the chemicals and operating conditions which exist in the actual application. As part of the analysis, you should consider the anticipated operating temperatures, the recommendations of the chemical supplier and actual test results where available. Contact your Local Chromalox Sales office for assistance or sheath material recommendations for chemicals and solutions not shown in this list.

Terminal Enclosures

Corrosion of electric immersion heaters is not limited to the sheath material. Frequently, application problems are related to contamination or corrosion of heater terminals and electrical connections. When selecting a heating element sheath material, also consider the location and environment of the terminal enclosure. Select an appropriate heater electrical terminal enclosure.

Temperatures & Watt Densities

Consider your selection of a heater sheath material very carefully. Once the material has been selected, design the application for sheath watt densities as low as practical and economical. Remember, the sheath of an immersion heater functions as a heat transfer surface and thus operates at temperatures above the temperature of the surrounding media. The higher the watt density, the higher the sheath temperature. The elevated media temperatures and the fluid movement around the sheath accelerate chemical reactions and may create severe localized corrosive conditions on the metal surface. Materials recommended for construction of your tank or vessel may not be suitable as the sheath material for the immersion heater.

Operating & Maintenance Factors for Maximum Heater Life

Sheath selection is only part of the solution to resolving potential corrosion problems. The ultimate life of a heating element sheath in a particular application will also depend upon a number of operating and maintenance factors. These factors are usually within control of the end user. To ensure maximum heater life and minimize sheath corrosion, Chromalox recommends the user:

1. **Maintain** the chemistry of the solution. Avoid carry-over from other processes.
2. **Avoid** depletion of bath chemistry. Maintain bath chemistry at optimum levels.
3. **Filter** or remove accumulating sludge, since sludge impedes flow of heat from element sheath and accelerates corrosion.
4. **Keep** process temperatures stable and as low as possible. Excessive operating temperatures mean shorter heater life.
5. **Avoid** galvanic corrosion. Avoid contact of the element sheath with dissimilar metals.
6. **Keep** immersion heaters out of the space between anode and cathode in electroplating processes. The effects of plating current may damage the element sheath.
7. **Examine** immersion heaters periodically for corrosion and sludge accumulation. Take corrective action to maintain continuity of operation.
8. **Electrically Ground** metal sheath heaters to the tank and, in turn, to earth for safety and protection of personnel against electrical shock. Consider the use of a ground fault circuit interrupter (GFCI) for optimum safety.

Table Legend to the Corrosion Guide

A = Good to Excellent service life

B = Fair to Good service life, expect some sheath corrosion

C = Depends on Conditions such as solution concentration, operating temperature and fluid flow

X = Not Suitable or Not Recommended

Blank = Data Incomplete or Not Available

WARNING — **Hazard of Electric Shock.** Any installation involving electric heaters must be effectively grounded in accordance with the National Electrical Code to eliminate shock hazard. All electrical wiring to electric heaters must be installed in accordance with the National Electrical code or local electrical codes by a qualified person. For maximum equipment protection, the National Electrical Code recommends Ground Fault Protection be provided for each branch circuit supplying electric heating equipment.

Warranty Disclaimer

Many factors that affect the corrosion of heater sheath material are beyond the control of the heater manufacturer. For this reason, Chromalox assumes no responsibility for any electric Immersion heater failure that can be attributed to corrosion. This is in lieu of any warranties, written or verbal, relative to heater performance in a corrosive environment.

Reference Data

Corrosion Guide for Electric Immersion Heaters *(cont'd.)*

Legend

A = Good to Excellent
B = Fair to Good
C = Depends on Conditions
X = Not Suitable
Blank = Data Not Available

Solution	Aluminum	Carbon Steel	Copper	Cast Iron	INCONEL® 600	INCOLOY® 800	Lead	MONEL® 400	304, 321, 347 SS	316 SS	20Cb-3 SS	C276 Hastelloy®	Quartz	Titanium	Teflon®[12]	Suggest Density[12]	Notes
Acetic Acid (100%)	X	X	X	X	C	B	X	BC	BC	**A**	BC	**A**	**A**	**A**	**A**	23	
Acetic Acid (50%)	C	X	X	X	X	B	X	B	C	**A**	**AC**	BC	**A**	**A**	**A**	15	
Acetone (100%)	**A**	BC	**A**	X	**A**	**A**	B	**A**	B	**A**	B	BC	**A**	**A**	**A**		2
Actane 70™															**A**		1
Actane 80™															**A**		1
Actane Salt™	CONTACT FACTORY																
Alcoa Bright Dip R5™													**A**		**A**		1
Allyl Alcohol	B	B	**A**	**A**	**A**	**A**	B	**A**	**A**	**A**	B	B	B	B	**A**		2
Alcohol	B	B	**A**	B	**A**	**A**	**A**	**A**	B	**A**	**A**	B	**A**	**A**	**A**	23 - 26	2
Alcorite™													**A**				1
Alkaline Cleaners									B						X	30 - 40	1
Alkaline Soaking Cleaners		B														30 - 40	1
Alodine™	CONTACT FACTORY																
Aluminum (Molten)	CONTACT FACTORY																
Aluminum Bright Dip													**A**		**A**		1, 9
Aluminum Chloride (Aqueous)	X	X	X	C	X	X	X	X	X	X	C	**A**	**A**	B	**A**		1
Aluminum Cleaners	X	C	X	C	**A**	**A**	X	**A**	**A**	**A**	B		X	B			1
Aluminum Sulphate (Sat.)	X	X	X	X	X	BC	B	X	BC	BC	B	BC	**A**	**A**	**A**		1
Alum	X	X	X	X	BC	BC	X	X	X	BC	BC	BC	**A**	**A**	**A**		1
Ammonia (Anhydrous)	C	**A**	X	X	**A**	C	C	**A**	B	**A**	**A**	**A**	**A**	**A**	**A**		
Ammonia (Gas)	X	C	X	X	B	C	C	X	**A**	**A**	B	**A**	**A**	**A**	**A**		
Ammonium Bifluoride	X	X	X	X	X	X	X	B	X	B	**AC**	B	X	X	**A**		
Ammonium Chloride (50%)	X	X	X	X	**A**	C	X	**A**	C	C	B	**A**	B	**A**	**A**		
Ammonium Hydroxide (25%)	B	BC	X	**A**	**A**	**A**	X	X	**A**	**A**	**A**	B	X	**A**	**A**		
Ammonium Nitrate	B	**A**	X	X	X	BC	X	X	**A**	**A**	**A**		**A**	C	**A**		
Ammonium Persulphate	B	X	X	X	C	C	C	X	C	B	B		**A**		**A**		
Ammonium Sulphate (< 40%)	X	X	X	X	B	**A**	B	B	C	B	B	B	**A**	**A**	**A**		
Amyl Alcohol	C	**A**	**A**	B	B	B	B	BC	B	B	B	B	**A**	**A**	**A**	23 - 26	2
Aniline	B	C	X	B	B	B	B	B	**A**	**A**	**A**	B	**A**	**A**	**A**		
Anodizing	X	X	X	X	X	X	**A**	X	X	X	**A**	**A**	**A**	X	**A**		
ARP 28™															**A**		1
ARP 80™ Blackening Salt													**A**				1
Arsenic Acid	X	X	C	X	X	B	X	X	B	B	B	C	**A**	X	**A**		
Asphalt	X	**A**	X	**A**	**A**	**A**	X	X	BC	B	**A**	B	**A**	**A**	**A**	6 - 10	2
Barium Hydroxide (Sat.)	X	B	X	B	B	B	X	C	B	B	B	B	**A**	**AC**	**A**		
Barium Sulphate	B	C	B	B	B	**AC**	B	B	B	B	B	B	**A**	**A**	**A**	55	
Beer	**A**	X	B		**A**	B	X	**A**	**AC**	**A**	**A**	**A**	**A**	B	**A**	30 - 40	
Black Nickel													**A**		**A**	23	5
Black Oxide									**A**							23	5
Black Liquor	X	X	X					BC	BC	BC	BC	C			**A**	15	
Bleach 5.5% Cl, Clorox™	X	X							BC	BC		**AC**			**A**	15 - 23	
Bonderizing™	SEE ZINC PHOSPHATE																
Boric Acid	X	X	C	X	C	**A**	C	BC	BC	BC	C	**A**	**A**	**A**	**A**		
Brass Cyanide									**A**								1
Bright Nickel													**A**	**A**		23	1, 5
Brine (Salt Water)	X	X	BC		**AC**	**AC**		B	C	B		**A**				55	10, 11
Bronze Plating		**A**							**A**								1
Butyl Alcohol (Butanol)	BC	BC	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	B	**A**	B	**A**		2
Cadmium Black													**A**				1
Cadmium Fluoborate															**A**		1
Cadmium Plating									**A**								
Calcium Chlorate	B	B	X	B	B	B	C	B	BC	BC	B	B		B	**A**		

See notes at end of table.

Reference Data

Corrosion Guide for Electric Immersion Heaters *(cont'd.)*

Legend

A = Good to Excellent
B = Fair to Good
C = Depends on Conditions
X = Not Suitable
Blank = Data Not Available

	Sheath Material																
	Aluminum	**Carbon Steel**	**Copper**	**Cast Iron**	**INCONEL® 600**	**INCOLOY® 800**	**Lead**	**MONEL® 400**	**304, 321, 347 SS**	**316 SS**	**20Cb-3 SS**	**C276 Hastelloy®**	**Quartz**	**Titanium**	**Teflon®[12]**	**Suggest Density[12]**	**Notes**
Solution	**Corrosion Rating**																
Calcium Chloride (Sat.)	BC	B	B	B	B	B	X	B	BC	B	B	**A**	**A**	**A**	**A**	23	
Carbon Dioxide - Dry Gas	**A**	B	BC	B	**A**	**A**	B	**A**	**A**	**A**	**A**	**A**	**A**	**AC**	**A**	10 - 23	
Carbon Dioxide - Wet Gas	**A**	X	X	X	**A**	**A**	B	**A**	B	B	**A**	B	**A**	BC	**A**	10 - 23	2
Carbon Tetrachloride	X	C	**AC**	X	**A**	**A**	**AC**	**A**	**A**	**A**	**A**	**AC**	**A**	**A**	**A**	23 - 26	1
Carbonic Acid (Phenol)	B	B	X	C	**A**	**AC**	X	**AC**	**A**	**A**	**A**	**A**	**A**	**A**	**A**		1
Castor Oil	BC	**A**	**AC**	**A**	**A**	**A**	**A**	**A**	BC	B	**A**	**A**	**A**	**A**		23 - 26	1
Caustic Etch	X	**A**	C	**A**	**A**	**A**	X	**A**	**A**	**A**	**A**	BC	X	**A**		15 - 26	6
Caustic Soda	SEE SODIUM HYDROXIDE																2
Chlorine Gas - Dry	X	C	C	X	B	**A**	X	**AC**	C	BC	B	B	**A**	X	B		
Chlorine Gas - Wet	X	X	X	X	X	X	X	C	X	X	X	BC	**A**	X	B		
Chloroacetic Acid	X	X	X	X	C	C	X	C	X	X	C	**AC**	**A**	**A**	**A**		
Chromic Acetate													**A**				1
Chromic Acid (40%)	X	X	X	X	X	X	B	X	BC	B	BC	B	**A**	**A**	X		
Chromic Anodizing													**A**				1
Chromylite													**A**				1
Citric Acid (Conc.)	X	X	X	X	B	**AC**	X	B	BC	**A**	**A**	**A**	**A**	**A**	**A**		1
Clear Chromate										**A**			**A**	**A**			1
Cobalt Nickel													**A**				1, 6
Cod Liver Oil					**A**	**A**			**A**	**A**	**A**					23 - 26	1
Copper Acid													**A**		**A**		1
Copper Bright									**A**								1
Copper Bright Acid													**A**				1
Copper Chloride	X	X	X	X	X	B	X	X	X	X	X	B	**A**	**A**	**A**		
Copper Cyanide	X		X	**A**	BC	B		X	B	B	B	**A**	**A**	**AC**	**A**		
Copper Fluoborate					B	B		B	B	B	B				**A**		
Copper Nitrate	X	X	X	X	X	BC		X	**A**	**A**	**A**	C	**A**	B	**A**		
Copper Pyrophosphate									**A**								1
Copper Strike		**A**		**A**					**A**								1
Copper Sulphate	X	X	X	X	BC	B	**A**	X	B	B	B	B	**A**	**A**	**A**		
Creosote	C	**A**	BC	**A**	B	B	X	B	B	B	B	B	**A**	**A**		6 - 15	2
Cresylic Acid 50%	C	BC		C	C	C	X	X	B	**A**	B	B	**A**	B	**A**		2
Deionized Water	SEE WATER																
Deoxidizer (Etching)													**A**				1
Deoxidizer (3AL-13 Non-Chrome)									**A**	**A**							1
Detergents	BC		**A**			B			**A**	B	**A**	**AC**		**A**	**A**	40 - 55	
Dichromic Seal		X		X					**A**	**A**			**A**				1
Diethylene Glycol	B	**AC**	B	**A**	B	B	**A**	B	**A**	**A**	**A**	B	**A**	**A**	**A**		1
Diversey-DS9333™													**A**				1
Diversey-511™													**A**				1, 5
Diversey-514™															**A**		1
Dowtherm™ (Diphenyl)	X	**A**	C			**A**		B	**A**	**A**	**A**	**A**				23	5
Dur-Nu™													**A**	**A**		23	1,5
Electro Cleaner		**A**							**A**								1
Electropolishing													**A**				1
Electroless Nickel													**A**	**A**	**A**		1
Electroless Tin (Acid)													**A**		**A**		1
Electroless Tin (Alkaline)										**A**				**A**			1
Enthone Acid - 80															**A**		1
Ethers, General	B	B	B	B	B	**A**	B	B	**A**	**A**	B	B	**A**	B	**A**		2
Ethyl Chloride	B	B	B	B	**A**	**A**	B	B	**A**	**A**	**A**	B	**A**	**A**	**A**		2
Ethylene Glycol	**A**	**A**	B	B	B	**A**	X	B	B	**A**	**A**	**A**	**A**	**A**	**A**	23 - 30	5
Fatty Acids	**A**	X	C	X	B	**AC**	X	B	BC	**A**	**A**	**A**	**A**	**A**	**A**	23 - 26	
Ferric Chloride	X	X	X	X	C	X	X	X	X	X	X	BC	**A**	**A**	**A**		
Ferric Nitrate (< 50%)	X	X	X	X	X	BC		X	BC	B	**A**	BC	**A**	**AC**	**A**		
Ferric Sulphate	X	X	C	X	C	C	B	C	BC	**AC**	**A**	**A**	**A**	**A**	**A**		
Fluoborate													**A**		**A**		1
Fluoboric Acid	X	**AC**	X					B	BC	**AC**	**AC**	**A**		X	**A**		
Fluorine Gas (Dry)	**AC**	X	X	X	**A**	C	C	**A**	**AC**	**A**	**A**	BC	C	X	C		
Formaldehyde (< 50%)	B	X	B	X	B	B	X	B	**AC**	**AC**	**A**	B	**A**	**A**	**A**		

See notes at end of table.

Reference Data

Corrosion Guide for Electric Immersion Heaters *(cont'd.)*

Legend	Sheath Material																
A = Good to Excellent B = Fair to Good C = Depends on Conditions X = Not Suitable **Blank** = Data Not Available	Aluminum	Carbon Steel	Copper	Cast Iron	INCONEL® 600	INCOLOY® 800	Lead	MONEL® 400	304, 321, 347 SS	316 SS	20Cb-3 SS	C276 Hastelloy®	Quartz	Titanium	Teflon®[12]	Suggest Density[12]	Notes
Solution	**Corrosion Rating**																
Formic Acid (10 - 85%)	B	X	C	X	B	B	X	B	**AC**	B	**A**	**A**	**A**	C	**A**		
Freon (F-11, F-12, F-22)	B	C	B		**A**	**A**	**A**	**A**	**A**	**A**	**A**	B				3 - 9	
Fruit Juices (Pulp)	B	X			B	**A**		**A**	BC	B	BC	**A**	B	**A**	**A**	30 - 40	
Fuel Oil (Normal)	B	**A**	B	**A**	B	**A**		B	**A**	**A**	**A**	B		**A**		6 - 15	2, 3, 7
Fuel Oil (Acid)	X	X	X	X	C	C		C	C	B	**A**			**A**		6 - 10	2, 3, 7
Gasohol	B	B	B		B	B		B	B	B	B	B				23 - 26	
Gasolene (Refined)	B	B	B	B	B	B		B	B	B	B	B	**A**			23	2, 5
Gasolene (Sour)	X	B	X	C	C	C		X	B	B	B	B	**A**		**A**	23	2, 3, 5
Glycerin (Glycerol)	**A**	B	**A**	B	**A**	**A**	B	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**		
Grey Nickel													**A**	**A**	**A**	23	1, 5
Hydrocarbons-Aliphatic	**A**	**A**	**A**	**A**	**A**	**A**		**A**	**A**	**A**	**A**	**A**	**A**			23 - 26	2
Hydrocarbons-Aromatic	**A**	**A**	**A**	**A**	**A**	**A**		**A**	**A**	**A**	**A**	**A**	**A**			23 - 26	2
Hydrochloric Acid (Dilute)	X	X	X	X	BC	BC	X	BC	X	X	X	**AC**	B	B	**A**	20 - 30	
Hydrochloric Acid (50%)	X	X	X	X	X	X	X	X	X	X	X	BC	X	X	**A**	15 - 25	
Hydrocyanic Acid (10%)	B	B	X	X	B	B	X	B	B	B	B		**A**		**A**		
Hydrofluoric Acid (Dilute)	X	X	X	X	BC	X	B	C	X	X	B	**A**	X	X	**A**	23	5
Hydrogen Peroxide (90%)	**A**	X	X	X	B	B	X	B	**AC**	**AC**	**AC**	**A**	**A**	B		23 - 26	
Indium													**A**		**A**		1
Iridite™ - #4 - 75, #4 - 73, #14,									**A**								
#14 - 2, #14 - 9, #18 - P										**A**							1
Iridite™ - #1, #2, #3, #4-C,																	
#4PC&S, #4P-4, #4-80, #4L-1,													**A**				
#4-2, #4-2A, #4-2P, #5P-1,	X	X	X	X	X	B	X	X	X	X	X	B	**A**	**A**	**A**		
#7, #7-P, #8, #8-P, #8-2, #12-P,	X		X	**A**	BC	B		X	B	B	B	**A**	**A**	**AC**	**A**		
#15, #17P, #18P													**A**				1
Iridite™ Dyes - #12L-2, #40, #80													**A**		**A**		1
Irilac™													**A**		**A**		1
Iron Fluoborate															**A**		1
Iron Phosphate (Parkerizing™)										**A**	B	B	**A**	**A**	**A**		
Isoprep™ Deoxidizer #187, #188										**A**							1
Isoprep™ Cleaner #186										**A**							1
Isoprep™ #191 Acid Salts															**A**		1
Jetal™									**A**								1
Jet Fuel JP-4	B	B			**A**		B	B	BC	B	BC	**A**		**A**			
Kerosene	B	B	BC		B	**A**	B	B	B	B	B	B				23 - 26	2
Lacquer Solvents	**A**	**A**	**A**	**A**	B	B	**A**	B	**A**	**A**	**A**		**A**	**A**		23 - 26	2
Lead Acetate	X	X	X	X	**A**	**A**	X	B	B	B	B	B	**A**	**A**	**A**		
Lead Acid Salts									B								1
Lime Saturated Water	X	B	B	B	B	B	X	B	B	**A**	B	**A**	X		C	23 - 40	
Linseed Oil	B	B	B		B	**A**	B	B	**A**	**A**	**A**		**A**		**A**	10 - 15	2
Lubricating Oil	B	**A**	**A**	**A**	**A**	**A**	**A**	B	B	B	**A**	B	**A**	**A**		23 - 26	7
Machine Oil		**A**		**A**	**A**	**A**	**A**	B	B	B		B	**A**	**A**		23 - 26	7
Magnesium Chloride	X	BC	B	X	**A**	B	X	B	C	B	B	**A**	**A**	**A**	**A**		
Magnesium Hydroxide	B	**A**	B	B	**A**	B	X	B	**A**	**A**	**A**	**A**	**A**	**A**	**A**		
Magnesium Nitrate	B	B	B	B	B	**A**	X	B	B	B	B	B	**A**	B	**A**		
Magnesium Sulfate	B	BC	BC	B	**AC**	B	B	**A**	B	B	B	B	**A**	B	**A**		
McDermid™ #629													**A**				1
Mercuric Chloride	X	X	X	X	X	X	X	X	X	B	BC	B	**A**	B	**A**		
Mercury	X	**A**	X	**A**	B	**A**	X	B	**A**	**A**	**A**	**A**	**A**	**A**	**A**	23 - 30	
Methyl Alcohol (Methanol)	C	B	B	B	**A**	**A**	B	**A**	B	B	B	**A**	**A**	**A**	**A**		2
Methyl Bromide	X	C	B	C	B	B	B	B	BC	**A**	**A**		**A**	**A**	**A**		
Methyl Chloride	X	X	B	C	B	C	C	B	**AC**	**AC**	**A**	B	**A**	**A**	**A**		
Methylene Chloride	C	BC	C	BC	B	B	B	**AC**	B	B	**AC**	**A**	**A**	**A**	**A**		
Milk	**A**	B	C		**A**	**A**	X	C	**A**	**A**	**A**	**A**				30 - 40	
Mineral Oil	B	B	B		**A**	**AC**	B	**A**	**AC**	B	**AC**		**A**	**A**	**A**	23 - 26	

See notes at end of table.

TECHNICAL INFORMATION

Reference Data

Corrosion Guide for Electric Immersion Heaters *(cont'd.)*

Legend **A** = Good to Excellent B = Fair to Good C = Depends on Conditions X = Not Suitable **Blank** = Data Not Available	Sheath Material: Aluminum	Carbon Steel	Copper	Cast Iron	INCONEL® 600	INCOLOY® 800	Lead	MONEL® 400	304, 321, 347 SS	316 SS	20Cb-3 SS	C276 Hastelloy®	Quartz	Titanium	Teflon®[12]	Suggest Density[12]	Notes
Solution	**Corrosion Rating**																
Muriatic Acid	SEE HYDROCHLORIC ACID																
Naphtha	A	A	A	B	A	A	A	A	A	A	A		A	A	A		2
Nickel Acetate	X									A							1
Nickel Chloride	X	X	X	X	AC	B	C	B	BC	BC	B	A	A	A	A	23	1, 5
Nickel Plate-Bright	X	X			BC				C	C	C		A	B	A	23	1, 5
Nickel Plate-Dull	X	X			BC				C	C	C		A	B	A	23	1, 5
Nickel Plate - Watts Solution													A	A	A	23	1, 5
Nickel Sulphate	X	X	C	X	C	C	B	C	B	B	B		A		A		
Nickel Copper Strike									AC	AC	AC						(Cyanide Free)
Nitric Acid (20%)	X	X	X	BC	BC	AC	X	X	AC	AC	A	AC	A	A	A	15	
Nitric & Hydrochloric Acid	X	X	X	X	C	X	X	X	BC	BC	C		A	X	A	15	
Nitric & 6% Phosphoric Acid										A			A		A	15	1
Nitric & Sodium Chromate										A			A		A		1
Nitric & Sulfuric Acid (50% - 50%)	X			C	X	X		X	AC	AC	AC				A	15	
Nitrobenzene	BC	B	BC	B	B	B	X	B	B	B	A	B	A	A	A		2
Oakite™ #67									A							30 - 40	1
Oleic Acid	C	BC	B	BC	A	AC	X	BC	AC	AC	B	B	A	AC	A		
Olive Oil	AC	B	B					B	B	B	B	AC		A		23 - 26	
Oxalic Acid (50%)	X	X	B	X	AC	AC	X	B	X	B	B	B	A	X	A		
Paint Stripper (High Alkaline)		A														30 - 40	1
Paint Stripper (Solvent)										A						23 - 26	1, 2
Paraffin	A	A	A	A	B	A		B	A	A	A	A				6 - 15	2, 7
Parkerizing™	SEE IRON PHOSPHATE																
Peanut Oil										B	B	A				23 - 26	
Perchloroethylene	B	A	B	A	A	A	B	A	AC	AC	B	B	A	A		23	
Petroleum Oils (Refined)	B	B	B	B				A	A	A	A		A			23 - 26	2, 3, 7
Petroleum Oils (Sour)	X	B	X	B				X	B	B						15 - 23	2, 3, 7
Phenol (Carbolic Acid)	B	B	X	C	A	AC	X	AC	A	A	A	A	A	A	A		
Phosphates (Generic)									BC	AC		B	X			23 - 40	1, 5, 9
Phosphate Cleaners									BC	AC		B			X	23 - 40	1, 5, 9
Phosphatizing										A					X	23	1, 5, 9
Phosphoric Acid (25% - 50%)	X	X	AC	X	BC	C	B	C	AC	BC	AC		A	X	A	23	5, 9
Picric Acid	BC	X	X	X	C	BC	X	X	BC	B	B	B	A		A		
Plating Solutions - Brass										B	AC	AC	A	A	A	23 - 35	1
Plating Solutions - Cadmium										B	AC	AC	A	A	A	23 - 35	1
Plating Solutions - Chrome (25%)	X	X	X		X	BC		X	BC	B	AC	AC	A	X	A	23 - 35	1
Plating Solutions - Chrome (40%)	X	X	X	X	X	X		X	BC	B	AC	AC	A	A	A	15 - 20	1
Plating Solutions - Cobalt									A				A			23 - 35	1
Plating Solutions - Copper												AC	A	AC	A	23 - 35	1
Plating Solutions - Gold (Cyanide)									AC	AC		AC	A	AC	A	15 - 20	1
Plating Solutions - Gold (Acid)		A											A	A		15 - 20	1
Plating Solutions - Nickel									AC	AC	AC	AC	A	A	A	23 - 35	1
Plating Solutions - Silver									AC	AC	AC	AC	A	A	A	23 - 35	1
Plating Solutions - Tin										C	AC	AC	A	X	A	23 - 35	1
Plating Solutions - Tin-Nickel													A		A	23 - 35	1
Plating Solutions - Tin-Alkaline		A							A							15 - 20	1
Plating Solutions - Zinc											AC	AC	A	A	A	23 - 35	1
Plating Solutions - Zinc Acid													A			15 - 20	1
Plating Solutions - Zinc Cyanide		A							A							15 - 20	1
Potassium Aluminum Sulphate	C	X	C						C	BC	A	BC	A	A	A		1
Potassium Bichromate	B	C	C	C	B	B		B	B	B	B	B	A	AC	A		
Potassium Chloride (30%)	X	BC	X	X	AC	B	C	AC	AC	A	AC	B	A	A			
Potassium Cyanide (30%)	X	BC	X	X	B	B	X	B	B	B	B	B	A	X	A		
Potassium - Hydrochloric Solution													A		A		1
Potassium Hydroxide (27%)	X	BC	C	X	B	B	X	B	BC	B	A	B	X	X	A		
Potassium Nitrate (80%)	A	B	BC	B	BC	B	B	B	B	B	B	B	A	A			
Potassium Sulphate (10%)	A	BC	BC	X	AC	BC	BC	A	A	A	A	A	A	A	A		

See notes at end of table.

Reference Data

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Solution	**Corrosion Rating**																
Reynolds Brightener													**A**		**A**		1
Rhodium Hydroxide													**A**		**A**		
Rochelle Salt - Cyanide		**A**							**A**								1
Ruthenium Plating													**A**		**A**		1
Silicon Oils	BC	B	**AC**						B	B						23 - 26	
Silver Bromide (10%)	X	X	X	X		**AC**		C	X	X	C	**AC**	**A**	**A**	**A**		
Silver Cyanide	X	C	X	C		**AC**		BC	**AC**	**AC**	**AC**	**AC**	**A**	**A**	**A**		
Silver Lume									**A**								1
Silver Nitrate	X	X	X	X	BC	BC	X	X	B	**AC**	B	**AC**	**A**	**AC**	**A**		
Soap Solutions	B	BC	BC	C	**AC**	**AC**	C	BC	BC	BC	BC	**AC**			**A**	55	3
Sodium Bichromate (Neutral)	C	B	C	**A**	B	B			B	B	B	B	**A**	C	**A**		
Sodium Bisulphate	X	C	X	X	BC	BC	C	BC	BC	BC	BC	B	**A**	BC	**A**		
Sodium Bromide (10%)	X	C	C	X	B	B		B	C	BC	B	B	**A**	C	**A**		
Sodium Carbonate	X	C	BC	C	**A**	**AC**	X	**A**	BC	B	**AC**	**AC**	C	**A**	**A**		
Sodium Chlorate	B	X	BC	X	**A**	**AC**	B	**AC**	BC	B	B	**A**	**A**	**A**	**A**		
Sodium Chloride	X	C	B	X	**AC**	**A**	B	**AC**	C	C	C	B	**A**	**A**	**A**		11
Sodium Citrate	X	X	X	X	**AC**	**AC**	X	B	BC	B	**A**	BC	**A**	**A**	**A**		
Sodium Cyanide	X	X	X	B	BC	BC	X	X	**AC**	**AC**	**A**	BC	**A**	C	**A**	30 - 40	
Sodium Dichromate (Hot Seal)	B	BC	X						BC	BC		**AC**		**A**	**A**		1
Sodium Hydroxide (50%)	X	C	X	C	**AC**	B	X	**AC**	**AC**	**AC**	B	**AC**	X	**AC**	**A**	15	6, 8
Sodium Hypochlorite (20%)	X	X	X	X	X	X	X	X	X	X	C	X	**A**	**A**	**A**	20	
Sodium Nitrate	**AC**	B	C	B	**A**	**A**	X	BC	**AC**	**AC**	**AC**	BC	**A**	**AC**	**A**	23	5
Sodium Peroxide (10%)	B	BC	X	C	BC	B	X	B	BC	B	BC	B	C		**A**		
Sodium Phosphate (Neutral)	X	B	B	B	B	B		B	B	B	B	B	**A**	B	**A**		
Sodium Salicylate		B		C	B	B		B	B	B	B		**A**		**A**		
Sodium Silicate	C	B	X	B	B	**AC**	X	**A**	BC	B	B	B		**A**	**A**		4
Sodium Sulfate	**AC**	B	BC	X	B	**AC**	X	BC	**AC**	**A**	B	B	**A**	C	**A**		
Sodium Sulfide (< 50%)	X	X	X	X	B	**AC**	X	B	BC	BC	BC	B	C	C	**A**		
Sodium Stannate		C		C	B	B		B	B	B	B		**A**		**A**		
Sodium Thiosulfate (Hypo)	C	X	X	C	B	B		BC	B	B	BC	BC	**A**	**AC**	**A**		
Solder Bath	X	X	X	B	X	X	X	X	X	X	X	X	X	X	X		4
Steam (Medium Pressure)		C	BC		**A**	**A**		**AC**	BC	BC	BC	B				10 - 15	
Stearic Acid	B	C	BC	C	B	**AC**	X	C	BC	**A**	B	**A**	**A**	**A**			
Sugar Solution	**A**	**A**	**A**	**A**	**A**	**A**	X	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	10 - 23	7
Sulfamate Nickel													**A**	**A**	**A**		1
Sulfamic Acid	X	X	C	X					BC		BC		**A**	**AC**	**A**		
Sulfur	**A**	X	X	X	**A**	**A**	X	BC	**A**	**A**	**A**	**A**	**A**	**A**			
Sulfur Chloride (Dry)	X	X	X	X	B	**AC**	C	X	BC	BC	BC	B	**A**		**A**		
Sulfur Dioxide (Dry)	C	**AC**	BC	C	B	**AC**	B	B	B	B	B	B	**A**	**A**		15 - 23	
Sulfur Dioxide (Wet)	X	X	X	X	X	BC	BC	X	X	B	BC	**AC**	**A**	**A**		10 - 20	
Sulfuric Acid (10% - 50%)	X	X	X	X	X	BC	**A**	X	X	X	B	**AC**	**A**	X	**A**	15	
Sulfuric Acid (98%)	X	X	X	X	X	BC	**A**	X	X	BC	**AC**	**AC**	**A**	X	**A**	15	
Sulfurous Acid	C	X	X	X	BC	**A**	**A**	X	X	BC	B	B	**A**	**A**	**A**		
Tannic Acid	X	X	C	X	B	B	X	B	B	B	B	B	**A**	**AC**	**A**		
Tin (Molten)	X		X		X		X	X	X	X	X				X	20	4
Trichloroethane	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**			
Trichlorethylene	**AC**	BC	BC	**A**	**AC**	**AC**	X	**A**	B	B	B	**A**	**A**	**A**	**A**	23	
Triethylene Glycol	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**			23	
Trioxide (Pickle)													**A**		**A**		1
Trisodium Phosphate	X	BC	BC	**A**			X	BC	**AC**	**AC**	**AC**	**AC**	X		**A**		
Turco™ 4181 (Alkaline Cleaner)										**A**							1
Turco™ 4008 (Descaler)										**A**						23	1, 5
Turco™ 4338 (Oxidizer)										**A**							1, 7
Turco™ Ultrasonic Solution										**A**							1
Ubac™													**A**				1
Udylite™ #66													**A**	**A**	**A**	23	1, 5
Unichrome™ CR-110													**A**		**A**		1
Unichrome™ 5RHS													**A**		**A**		1

See notes at end of table.

Reference Data

Corrosion Guide for Electric Immersion Heaters *(cont'd.)*

Legend	Sheath Material															
A = Good to Excellent B = Fair to Good C = Depends on Conditions X = Not Suitable **Blank** = Data Not Available	Aluminum	Carbon Steel	Copper	Cast Iron	INCONEL® 600	INCOLOY® 800	Lead	MONEL® 400	304, 321, 347 SS	316 SS	20Cb-3 SS	C276 Hastelloy®	Quartz	Titanium	Teflon®[12]	Suggest Density[12]	Notes
Solution	**Corrosion Rating**															
Vegetable Oil	B	B	BC		B	**A**		B	B	B	**A**	**AC**				23 - 26	
Water, Deionized	X	X	X	X	**A**	**A**		C	**A**	**A**	**A**	B				50 - 75	10
Water, Demineralized	X	X	X	X	**A**	**A**		C	**A**	**A**	**A**	B				50 - 75	10
Water, Pure (Distilled)	X	X	X	X	**A**	**A**		**A**	**A**	**A**	**A**	**A**				50 - 75	10
Water, Process	C	X	B		**A**	**A**		B	BC	BC	**A**	B	**A**	**A**	**A**	50 - 75	10, 11
Water, Potable	C	X	B		**A**	**A**		B	BC	BC	**A**	B	**A**	**A**	**A**	50 - 75	10, 11
Water, Salt Brine	X	X	BC		**AC**	**AC**		B	C	BC		**A**				55	10, 11
Water, Sea	X	X	BC	X	BC	**AC**		**A**	C	BC	BC	**AC**	**A**	**A**	**A**	55	10, 11
Watts Nickel Strike													**A**				1
Whiskey	X	X	BC		B			**A**	**A**	**A**	B	**AC**				55	2
Wines	X	X	BC					B	**A**	**A**	B	**A**				55	
Wood's Nickel Strike													**A**				1
Yellow Dichromate										**A**			**A**				1
Zinc (Molten)	X		X		X	X	X	X	X	X	X			X	X		
Zinc Chloride	X	X	X	X	B	BC	X	BC	X	B	B	B	**A**	B	**A**		
Zinc Phosphate										**A**					X	23	1, 5
Zincate™		**A**							**A**								1

Actane™ - Ethone Inc.
Alcoa™ - Aluminum Company of America
Alcorite™ - Fredrick Gumm Chemical Co.
Alodine™ - Amchem Products Inc.
ARP™ - Allied-Kelite Products Div.
Bonderizing™ - Parker Div. OMI Corp.
Clorox™ - The Clorox Co.
Diversey™ - Diversey Chemical Co.
Dowtherm™ - Dow Chemical Co.
Dur-Nu™ The Duriron Co., Inc.
Iridite™ - Allied-Kelite Products Div.
Irilac™ - Allied-Kelite Products Div.
Isoprep™ - Allied-Kelite Products Div.
Jetal™ - Technic Inc.
MacDermid™ - MacDermid, Inc.
Oakite™ - Oakite Products Inc.
Parkerizing™ - Parker Div. OMI Corp.
Turco™ - Turco Products Div., Purex Corp.
Ubac™ - The Udylite Co., OMI Corp.
Udylite™ - The Udylite Co., OMI Corp.
Unichrome™ - M & T Chemicals Inc.
Zincate™ - Ashland Chemical

Notes —

1. This solution is a mixture of various chemical compounds or is a proprietary trade name whose identity and proportions are unknown or subject to change without our knowledge. Check the chemical supplier or manufacturer to confirm the choice of sheath material or alternate sheath materials that may be suitable.
2. **CAUTION** — Flammable material.
3. Chemical composition varies widely. Contact the chemical supplier for specific recommendations.
4. Direct immersion heaters are usually not practical. Recommend using clamp-on heaters on the outside surface of a cast iron pot.
5. Element surface loading should not exceed 23 watts per square inch.
6. For concentrations greater than 15%, element surface loading should not exceed 15 watts per square inch.
7. Concentrations vary widely. See suggested watt density chart or contact your Local Chromalox Sales office.
8. Remove crusts at liquid level.
9. Clean often.
10. Passivate stainless steel for maximum corrosion resistance.
11. Stainless steel materials may be subject to chloride or stress corrosion cracking in this environment.
12. Suggested watt densities do not apply to Teflon® coated heaters. Lower watt densities may be required.

Technical Information

NEMA Enclosures & Chromalox Equivalents

NEMA Enclosures for Non-Hazardous Areas

The National Electrical Manufacturer's Association (NEMA) publishes a classification system for electrical enclosures. The NEMA classification or type indicates the exposure or environment for which the enclosure was designed. While Chromalox E1, E2, E3 and E4 enclosures are designed for applications similar to the NEMA types, they are not identical due to modifications required to adapt the housings to heater configurations. Condensed descriptions of the NEMA non- hazardous enclosure types are listed below with the Chromalox equivalents indicated. The condensed descriptions are not intended to be complete representations of the National Electrical Manufacturers Association standards for electrical enclosures. For complete details on NEMA enclosure requirements refer to NEMA Std. No. 250.

Type 1 Enclosures — are for indoor use in locations where unusual service conditions do not exist. Intended primarily to provide protection against contact with the enclosed equipment and limited amounts of falling dirt. **(Chromalox E1 or General Purpose enclosures.)**

Type 2 Enclosures — are for indoor use providing protection against limited amounts of falling water and dirt.

Type 3 Enclosures — are for outdoor use providing protection against windblown dust, rain, and sleet and damage from external ice formation on the enclosure.

Type 3R Enclosures — are similar to Type 3 except Type 3R provides protection against falling rain.

Type 3S Enclosures — are for outdoor use protecting against windblown dust, rain, and sleet and providing for operation of external mechanisms when ice laden.

Type 4 Enclosures — are for indoor or outdoor use providing protection against windblown dust and rain, splashing water, and hose-directed water and remain undamaged by the formation of ice on the enclosure. **(Chromalox E4 Moisture Resistant or E2 Moisture and Explosion Resistant enclosures.)**

Type 4X Enclosures — are similar to Type 4 except Type 4X also protects against corrosion.

Type 5 Enclosures — are for indoor use and protects against dust and falling dirt.

Type 6 Enclosures — are for indoor or outdoor use providing protection against the entry of water during temporary submersion at a limited depth and remain undamaged by ice on the enclosure.

Type 6P Enclosures — are similar to Type 6 except Type 6P protects against the entry of water during prolonged submersion at a limited depth.

Type 12 Enclosures — are intended for indoor use providing protection against dust, falling dirt and dripping non-corrosive liquids. **(Chromalox E2 and E4 enclosures.)**

Type 12K Enclosures (knockouts) — are similar to Type 12 except they are provided with knockouts. Knockouts only permitted in either or both the top or bottom walls.

Type 13 Enclosures — are for indoor use providing protection against lint, dust, spraying of water, oil and non-corrosive coolant. **(Chromalox E2 enclosures may be used.)**

The table below lists a comparison of the characteristics of NEMA and Chromalox enclosures for Non-Hazardous areas.

Note — For Classified (Hazardous) Location enclosures, refer to NEMA Enclosures and Hazardous Location Heaters elsewhere in this section.

Comparison of Specific Applications of Enclosures for Non-Hazardous Locations

Provides a Degree of Protection Against the following Environmental Conditions	Type of Enclosure														Chromalox®			
	1	2	3	3R	3S	4	4X	5	6	6P	11	12	12K	13	E1	E2	E3	E4
Incidental contact with the enclosed equipment	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Falling dirt	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X
Falling liquids and light splashing		X				X	X		X	X	X	X	X	X		X	X	X
Dust, lint, fibers and flyings — Not Class III						X	X	X	X	X		X	X	X		X	X	X
Hosedown and splashing water						X	X		X	X						X		X
Oil and coolant seepage												X	X	X		X	X	X
Oil or coolant spraying and splashing														X		X		
Windblown dust			X		X	X	X		X	X						X	X	X
Rain, snow and sleet			X	X	X	X	X		X	X						X		
Sleet					X													
Corrosive agents							X			X	X							
Occasional temporary submersion									X	X								
Occasional prolonged submersion										X								

Technical Information

NEMA Enclosures & Hazardous Location Heaters

NEMA Enclosures for Classified Locations (Hazardous)

The following are condensed descriptions of the NEMA enclosure types for Classified (Hazardous) Locations. The Chromalox enclosures equivalent to the NEMA description are indicated. The Chromalox enclosure may not be indentical to the NEMA description due to modifications required to adapt the housing to heater configurations. The NEMA enclosure descriptions are not intended to be complete representations of the National Electrical Manufacturers Association standards for electrical enclosures. For complete details on NEMA enclosure requirements, refer to NEMA Std. No. 250.

Type 7 Enclosures — are intended for indoor use in locations classified as Class I, Groups A, B, C and D as defined in the National Electrical Code. **(Chromalox E2, E3 or Explosion Resistant enclosures.)**[2]

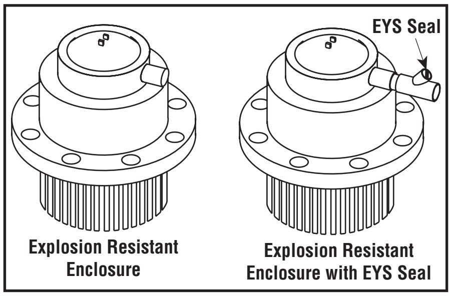
Type 8 Enclosures — are intended for indoor or outdoor use in locations classified as Class I, Groups A, B, C and D as defined in the National Electrical Code. **(Chromalox E2 enclosures.)**[2]

Type 9 Enclosures — are intended for indoor use in locations classified as Class II, Groups E, F and G as defined in the National Electrical Code. **(Chromalox E2, E3 or Explosion Resistant enclosures.)**

Type 10 Enclosures (MSHA) shall be capable of meeting the requirements of the Mine Safety and Health Administration, 30 C.F.R., Part 18.

Chromalox Enclosures for Electric Heaters in Classified Locations

Chromalox has terminal enclosures specifically designed for use on electric heaters installed in Classified (Hazardous) areas. These enclosures are identified as Type E2 and E3. Typical flange heaters with E2 hazardous area terminal enclosures are shown below.



E2 enclosures are supplied with gaskets and are suitable for both indoor and outdoor locations. E2 enclosures meet the moisture and explosion-resistant requirements for NEMA 4, 12, 7, 8 and 9 applications. E3 enclosures are usually not furnished with gaskets and are intended primarily for indoor and dry locations. See table below.

Electric Heaters for Hazardous Locations

Chromalox provides a wide variety of electric immersion and air heaters for use in hazardous locations. These heaters are listed by Underwriters Laboratories (UL) or certified by Canadian Standards Association (CSA). Heaters designed and certified for Class I or II Division I hazardous locations can be used in Division 2 areas in the same class.

Immersion Heaters — Screw plug and flanged immersion heaters are available with terminal enclosures CSA or CSA NRTL/C certified for Class I, Groups B, C and D and Class II Groups E, F and G. Supplemental low-liquid level controls are required for maximum safety and equipment protection when immersion heaters are used in hazardous locations.[2]

Circulation Heaters — Many water and oil circulation heaters are available with terminal enclosures CSA or CSA NRTL/C certified Class I, Groups B, C and D and Class II, Groups E, F and G. Supplemental controls are required for maximum safety and equipment protection when circulation heaters are used in hazardous locations

Air Heaters — Blower type air heaters (CXH-A) are available for Class I, Division I, Groups C and D and Class II, Division I, Groups E, F and G with UL, UL-C, and/or CSA certification. Convection type air heaters (CVEP) are available for use in Class I, Division I, Groups B, C and D hazardous locations. Convection type air heaters (FPEP and CEP) are available for use in Class I, Division I, Groups C and D and Class II, Division I Groups E, F and G.

Specialty Products & Components —Chromalox has designed, manufactured and provided certification on a large number of specialty products for hazardous areas and other special applications. These products include UL Recognized Components (finned tubular elements), duct heaters and special aircraft ground support equipment. Contact your Local Chromalox Sales office for assistance in designing equipment or solving any unique electric heating application for hazardous areas.

Comparison of Specific Applications of Enclosures for Indoor Hazardous Locations

Atmospheres Containing	Class	Group	NEMA				Chromalox	
			7	8	9	10	E2	E3
Acetylene	I	A	X	X				
Hydrogen, Manufactured Gas	I	B	X	X			X[1,2]	X[1,2]
Diethel Ether, Ethylene, Cyclopropane	I	C	X	X			X	X
Gasoline, Hexane, Butane, Naptha, Propane, Acetone Toluene or Isoprene	I	D	X	X			X	X
Metal Dust	II	E			X		X	X
Carbon Black, Coal Dust, Coke Dust	II	F			X		X	X
Flour, Starch, Grain Dust	II	G			X		X	X
Fibers, Flyings	III	G			X		X	X
Methane with or without Coal Dust	MSHA					X		

1. Requires seals in the conduit adjacent to the terminal enclosure.
2. For EMT and MT styles, Class 1 Group B; Divisions 1& 2, consult factory.

Technical Information

Hazardous Locations & Electric Heater Applications

Hazardous Locations (NEC)[5]

Articles 500 to 504 in the National Electrical Code (NEC) define the requirements for electrical and electronic equipment and wiring in locations where fire or explosion hazards may exist. In Article 500, hazardous locations are categorized by class. Classes are defined as follows:

Class I — Groups A, B, C & D - Division 1 or 2 Temperature Rating T1 - T6

Class II — Groups E, F & G - Division 1 or 2 Temperature Rating T1 - T6

Class III — Division 1 or 2

Class I, II & III (NEC 500)

Hazardous location classes are identified based on the explosive material present. The following information is an interpretation and summary of each class and a discussion of some of the conditions to be considered when using electric heaters in these areas. Refer to the National Electrical Code and local authorities for the proper classification and requirements of a specific hazardous location.

Class I Locations (Gases) are areas where flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures (NEC 500-5).

Class II Locations (Dust) are areas where the presence of combustible dust presents a fire or explosion hazard (NEC 500-6).

Class III Locations (Fibers) are areas made hazardous because of the presence of easily ignitable fibers or flyings, but in which such fibers or flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures (NEC 500-7).

Group Classification, Class I & II[6]

Certain chemicals create higher explosive pressures and more heat than others when ignited. In Class I and II hazardous locations, chemical families are further classified by Groups. Group classification involves determination of the maximum explosion pressures, the maximum safe clearance or gap between clamped enclosure joints and the minimum ignition temperature of the atmospheric mixture for a particular chemical.

NEC requires that any electrical equipment approved for use in a hazardous location must be approved for the class and for the specific group (gas or dust) that will be present. Groups are identified as A, B, C, D, E, F and G and are explained as follows:

Class I — Gases[6] *(NEC 500-3a)*

Combustible and flammable gases and vapors in Class I are sub-divided into four groups A, B, C and D. Group A gases create the most explosive pressure and therefore are the most difficult to contain. Group B is next, then Group C with Group D being the lowest. Third party listings of electrical equipment for Group A or B are more difficult to obtain than Group C or D. Individual gases are further defined by ignition temperature (see Temperature Ratings).

Group A —

Gases include:	Ignition Temperature	
	°C	°F
Acetylene	305	581

Group B —

Gases include:	Ignition Temperature	
	°C	°F
Butadiene[1]	420	788
Ethylene oxide[2]	429	804
Hydrogen & mfg gases > 30% hydrogen (by volume)	400	752
Propylene oxide[3]	449	840

Group C —

Gases include:	Ignition Temperature	
	°C	°F
Acetaldehyde	175	347
Cyclopropane	500	932
Diethyl ether	160	320
Ethylene	450	842
Dimethyl hydrazine	249	480

Group D — is the largest group and includes many of the common petroleum products.

Gases include:	Ignition Temperature	
	°C	°F
Acetone	465	869
Alcohol's		
1-butanol (butyl)	365	689
Amyl alcohol	300	572
Butyl alcohol (ter)	480	896
Ethanol (ethyl)	356	689
Isobutyl alcohol	427	800
Isopropyl alcohol	399	750
Methanol (methyl)	385	725
Propyl alcohol	440	824
Ammonia[3]	651	1204
Benzene	560	1040
Butane	405	761
Ethane	515	959
Ethyl acetate	427	800
Ethylene dichloride	413	775
Gasoline		
(56 - 60 octane)	280	536
(100 octane)	456	853
Heptanes	280	536
Hexanes	225	437
Isobutyl acetate	421	790
Isoprene	220	428
Methane (Nat. gas)	482/632	900/1170
Methyl ethyl ketone	516	960
Petroleum naphtha[4]	288	550
Octanes	220	428
Pentanes	260	500
Propane	450	842
Vinyl acetate	427	800
Vinyl chloride	472	882
Xylenes	530	986

Notes —

1. **Group D** equipment may be used for this atmosphere if isolated in accordance with Section 501-5(a) by sealing all conduit(s) 1/2 inch or larger (within 18 inches of the enclosure).
2. **Group C** equipment may be used for this atmosphere if isolated in accordance with Section 501-5(a) by sealing all conduit(s) 1/2 inch or larger (within 18 inches of the enclosure).
3. **For Classification of Ammonia Atmospheres** see Safety Code for Mechanical Refrigeration (ANSI/ASHRAE 15-1992) and Safety Requirements for the Storage and Handling of Anhydrous Ammonia (ANSI/CGA G2.1-1989).
4. **Also Known By** the synonyms benzine, ligroin, petroleum ether or naphtha.
5. **NEC and National Electrical Code** are registered trademarks of the National Fire Protection Association.
6. **For a Complete List** defining properties of flammable liquids, gases, solids or dusts, refer to the latest edition of **NFPA 325, NFPA 497 or NFPA 499.**

Technical Information

Hazardous Locations & Electric Heater Applications

Class II — Dust[1] (NEC 500-3b)

Groups E, F and G (Class II) — Combustible dusts are divided into Groups E, F and G. Classification involves investigation and testing of the assembled enclosure including the clamped joints, clearances and shaft openings. The blanketing effect of layers of dust, the electrical conductivity and the ignition temperature of the dust are also evaluated.

Group E Atmospheres contain metal dust, including aluminum, magnesium, their commercial alloys and other metals of similarly hazardous characteristics having resistivity less than 10^5 Ohm-cm.

Group F Atmospheres contain combustible carbonaceous dusts, charcoal, coal or other atmospheres containing these dusts sensitized by other hazardous materials and having resistivity greater than 10^2 through 10^8 Ohm-cm.

Group G Atmospheres contain combustible dusts such as flour, grain, wood and chemicals having resistivity of 10^5 Ohm-cm, or greater.

Class III — Fibers (NEC 500-7a)[1]

Atmospheres containing easily ignitable fibers such as rayon, cotton, flax, jute, hemp, kapok, excelsior and similar materials.

Divisions in Hazardous Locations

The NEC further sub-divides hazardous locations into Divisions (Div. 1 and 2). The requirements for Division 2 are less stringent than for Division 1. The two divisions are discussed in the following paragraphs.

Division I Locations

Class I, Division 1 — NEC 500-5(a) is an area where the hazard can exist under normal operating conditions. Included are areas where flammable or combustible liquids are transferred from one container to another, open vats, paint spray booths or any location where ignitable mixtures are used. Also included are locations where a hazard is caused by frequent maintenance, repair or equipment failure.

Class II, Division 1 — NEC 500-6(a) is an area where combustible dust is normally in the air in sufficient quantities to produce ignitable mixtures or where mechanical failure or abnormal equipment operation might produce ignitable mixtures. Locations also include operations where hazards exist because of frequent mechanical failure of machinery or equipment and where electrically conductive combustible dusts (all Group E and some Group F) are present in hazardous quantities.

Class III, Division 1 — NEC 500-7(a) is an area where easily ignitable fibers or materials producing combustible flyings are handled, manufactured or used.

Division 2 Locations

Class I, Division 2 — NEC 500-5(b) is an area where ignitable gases or vapors are handled, processed or used, but which are normally in closed containers or closed systems from which they can only escape through accidental rupture or breakdown of such containers or systems.

Class II, Division 2 — NEC 500-6(b) is an area where combustible dust is not normally in the air in sufficient quantities to produce ignitable mixtures or interfere with the operation of electrical equipment, or where dust is present as a result of infrequent malfunctioning of processing or handling equipment. Included are situations where combustible dust accumulations may interfere with the safe dissipation of heat from electrical equipment. No electrically conductive dusts as defined in NEC 502-1, (last sentence) are included in Class II, Div. 2 atmospheres.

Note — There is no Division 2 classification for Class II, Group E.

Class III, Division 2 — NEC 500-7(b) is an area where easily ignitable fibers are stored or handled.

Class I — Adjacent Divisions

In most indoor areas with adequate partitions, Div. 1 and 2 are self-contained areas. With partitions, a Div. 1 area may exist adjacent to a non-hazardous area. However, outdoors or in large indoor areas with few or no partitions, Class I, Div. 1 and Class 1, Div. 2 areas usually exist adjacent to each other. The Div. 1 location being near the point of vapor release and Division 2 is at a given distance fromthe release point of the flammable liquid. Where the spread of flammable vapors and gases is not contained by adequate partitions, the area designated as Class I, Div. 2 serves as a “transition zone” between the hazardous and non-hazardous area. Div. 1 is the hazardous area where flammable gases or vapors are released from the liquid. Div. 2 is the area further away from the point of release, where the gases or vapors are not normally of sufficient concentration to produce an ignitable mixture.

Class I & II — Temperature Ratings

Originally, equipment in each group had one maximum temperature rating. The maximum for Groups A, B and D was 280°C (536°F) and Group C was 180°C (356°F). Recognizing that chemicals and gases have different ignition temperatures, NEC revised the temperature ratings accordingly. Heat producing equipment must now be identified by Class, Group, Division and “T” rating. The “T” rating shall not exceed the ignition temperature of the specific gas, vapor or dust present. Values for “T” ratings for Class I and II equipment are shown in the table below:

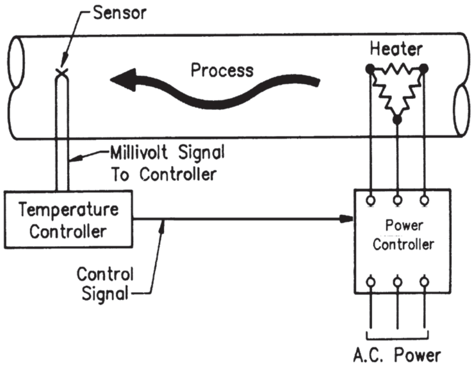
T-Ratings for Class I and II

Maximum Degrees (°C)	Temperature Degrees (°F)	Identification “T” Number
450	842	T1
300	572	T2
280	536	T2A
260	500	T2B
230	446	T2C
215	419	T2D
200	392	T3
180	356	T3A
165	329	T3B
160	320	T3C
135	275	T4
120	248	T4A
100	212	T5
85	185	T6

Note 1 — For a complete list defining properties of flammable liquids, gases, solids or dusts, refer to the latest edition of NFPA 325, NFPA 497 or NFPA 499.

Technical Information

Control Systems Selection Guidelines



Closed Loop Control System

Topics:

- Process controls, overtemperature controls, level controls, sensors, power controls, and panels.

Now that you have selected the heater(s) for your process, it is time to choose control components, panels, and sensors, to provide the desired results.

System Considerations

In order to assemble a complete control system, you will need the following information:

- **Voltage, wattage, current** (calculated from voltage and wattage),
- **Number of zones:** (different sections controlled differently),
- **Area location or classification:** (indoor, outdoor, explosion hazard), and
- **The desired process temperature range,** as well as permitted deviations should be specified. Close control and/or control of one pass heating of gas or liquids will probably require electronic control.
- **Process accuracy issues:** For large mass processes (big tanks, large blocks of metal) where the temperature won't or can't move quickly, and the temperature requirement is not critical, mechanical bulb and capillary thermostats can usually be used, or if electronic control with indication is needed a simple On/Off controller with a contactor is necessary.
- **Process speed:** For processes having low mass, fast, accurate control is important. A proportional or PID controller with an SCR power controller would be a good choice.
- **Process upset:** If the process is subject to upset, (oven door opened for new batch, for instance), a PID control will be required for good results. This is also the case if heating liquid or gas (air) in one pass. An SCR will be needed as well.
- **Environmental (ambient conditions):** Process controls, overtemperature controls, and accessories must be selected with the surrounding area in mind. Wet, dry, and explosion hazard areas must be considered, as well as the ambient temperature range the equipment will operate in. Mechanical controls should not be exposed to temperatures above their stated range. Electronic controls are designed to operate in an ambient temperature of above 32˚F, and below a stated maximum, usually 120 or 140˚F.
- **Safety:** An overtemperature control should be included to protect process, area, heater(s), and/or product in the event of a primary control failure, or interruption of flow in moving systems. If the power control is an SCR, a contactor or shunt trip should be provided so the load can be shut down, even if the SCR's are shorted. If heating confined liquid or gas, an approved mechanical temperature/pressure relief valve is also required. For some areas, ASME certification may be required on pressure vessels.

System Components

These parameters will help you determine the system components you need:

- **Sensor:** This can be a bulb and capillary, thermocouple, RTD or non-contact IR sensors.
- **Temperature Controller:** This can be a mechanical bulb & capillary controller or an electronic controller to accurately control the process.
- Overtemperature Controller (Limits): For protection of the process and/or the heater sheath, an overtemperature controller should always be used to ensure safe operation in the event of process control failure and/ or interruption of flow in dynamic systems.
- Power Controller: In order to switch the heater load, either mechanical contactors or SCR's are needed.

Sensors

The sensor is the device measuring the temperature or other variable of a system. It is usually in direct contact with the heated medium and must be specified to handle the temperature and conditions of the process. Electronic controllers convert the signal from RTD's and thermocouples to a temperature reading.

Thermocouples

Rugged and versatile, with many selections for various temperature ranges, thermocouples consist of two different material wires welded together. These devices produce a very small DC voltage, depending on temperature and thermocouple type. The controller or overtemperature controller, interprets this voltage, and compares it with internal standards, displaying and/or controlling a temperature.

Advantages: Lots of choices, rugged, inexpensive.

Technical Information

Control Systems Selection Guidelines *(cont'd.)*

Disadvantages: Output is not linear with temperature when new thermocouples are within 2 to 3˚F accuracy. Thermocouple alloys age, which affects accuracy further.

Microprocessor controls are best at interpreting TC voltage curves. Thermocouple wire of the same type as the thermocouple (i.e. type J for J), must be used to connect the thermocouple to the controller. **Note:** The red lead is always the negative lead in USA thermocouple color-coding.

RTD'S

RTD's or Resistance Temperature Detectors, provide a resistance change linearly related to a temperature change. The most common is the 100-ohm platinum. The controller measures the change of resistance, and relates it to temperature.

Advantages: RTD's are much more accurate and more linear than thermocouples. Standard copper wire can be used to connect the sensor to the control. Since the signal is larger than a thermocouple signal, it is more immune to electrical noise. Three wire RTD's can also be run longer distances than thermocouples.

Disadvantages: RTD's are more costly than thermocouples, and less rugged. In addition, they should not be exposed to a temperature higher than their rated operating temperature. Don't weld or braze them.

Transmitters

A transmitter is an electronic circuit that converts the low level signal of a thermocouple, RTD, or other device or parameter (like humidity) to a current loop, typically a 4 to 20mA signal. This produces better immunity to noise than the low-level signal by itself.

Advantage: Longer control signal runs are possible without interference.

Disadvantage: Increased cost of installation.

Infrared Sensor

IR (non-contact) sensors provide a control signal related to the temperature of an object, without touching the object. The IR sensor "looks" at the process, and adds or reduces heat as required. They are often used in continuous processes where material is passing through a convection oven or under radiant heaters.

Advantages: Provides good closed loop control for flowing processes or surface drying applications.

Disadvantages: More expensive than contact sensors. Does not work well for shiny objects. A temperature control is still required to interpret the output of an IR sensor, compare it to the setpoint, and operate a power controller.

Sensor Placement

Placement is very important for a good control result. The temperature control, no matter how smart its PID loop is, can only process the information supplied to it.

Where possible, in a block type system (like a platen) the heater, sensor and load (die) should be as close together as possible. This minimizes thermal lag, and provides good response to changes. (See Figure 1)

In a stable system, where the heater is separated from the load, the sensor can be placed near the heater to provide for close heater control. The load will be cooler than the sensed temperature by the drop through the heat transfer path from the heater to the load. This is not good for changing condition systems. (See Figure 2)

A compromise may be provided for by placing the sensor between the heater and the load. This is good for fairly stable systems where the heat demand may be alternately constant or variable.(See Figure 3)

For changing systems, the sensor can be placed closer to the load to respond to changing load requirements. The sensor farther from the heater increases the thermal load. This will cause overshoots and undershoots. A PID controller is required to minimize the temperature cycling. (See Figure 4)

In conclusion, it is important that the heater, sensor and load be as close as possible. The sensor should always be between the heater and the load.

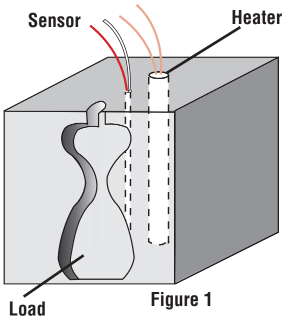


Figure 1

Best Solution

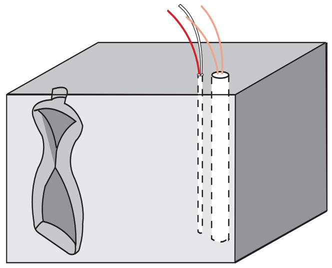


Figure 2

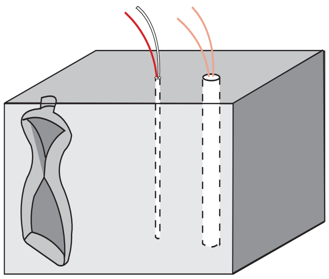


Figure 3

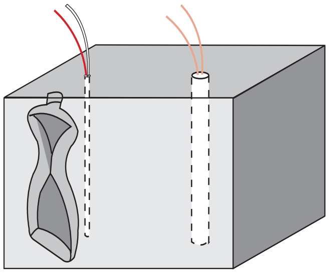


Figure 4

Technical Information

Control Systems Selection Guidelines *(cont'd.)*

Wiring

Thermocouple extension wire of the same type as the thermocouple (J for J) must be used to connect controls to sensors. Many varieties of thermocouple extension wire are available, with insulation types for different environments. For thermocouples, the negative(-) lead is always red in the USA. Copper wire can be used for RTD's and 4-20mA signals. RTD's and thermocouples have low level electrical signals. Shielding is recommended. The shield should only be grounded at one end (the controller end) to avoid ground loops. Sensor wires should not be run in the same conduit as power wires to prevent interference.

Environmental and Safety

Sensors and accessories must be selected with the surrounding area in mind. Wet, dry and explosion hazard areas must be considered, as well as the ambient temperature range the equipment will see. Insulation for extension wiring must also be able to withstand the ambient conditions. Electronic sensors and transmitters are designed to operate above 32˚F, and below a stated maximum, usually 120 or 140˚F. See specific unit for operating ambient temperature range.

Choosing a Sensor

Selection Criteria

The most popular sensor is the thermocouple, and of those, J and K are most frequently used. Select a TC with a temperature range matched to your process. For best accuracy, use an RTD unless your temperature range does not permit.

Service issues: When placing a sensor through the side of a tank of liquid, consider using a sensor with a thermowell, so the sensor can be replaced without draining the tank.

Thermocouple Type	Temp Range	Recommended Temperature Range	Temperature Range for Standard Limits of Error	Standard Limits of Error	Negative Wire Color	Positive Wire Color	Jack & Plug Color	Application Information
J	-300 to 1400˚F	32 to 1400˚F	32 to 527˚F (0 to 275˚C) 559 to 1400˚F (293 to 760˚C)	+/- 4˚F +/- .75%	RED	WHITE	BLACK	Suitable for vacuum, reducing, or inert atmospheres, oxidizing atmosphere with reduced life. Iron oxidizes rapidly above 1000˚F (538˚C), so only heavy gauge wire is recommended for high to sulphurous atmospheres above 1000˚F (538˚C).
K	-450 to 2300˚F	32 to 2300˚F	-328 to -166˚F (-200 to -110˚C) -166 to 32˚F (-110 to 0˚C) 32 to 559˚F (0 to 293˚C) 559 to 2282˚F (293 to 1250˚C)	+/- 2% +/- 4˚F +/- 4˚F +/- .75	RED	YELLOW	YELLOW	Recommended for continuous oxidizing or neutral atmospheres. Mostly used above 1000˚F (538˚C). Subject to failure if exposed to sulphur. Preferential oxidation of chromium in positive leg at certain low oxygen concentrations causes 'green rot' and and large negative calibration drifts most serious in the 1500-1900˚F (816-1038˚C) range. Ventilation or inert-sealing of the protection tube can prevent this.
T	-450 to 700˚F	-300 to 700˚F	-328 to -89˚F (-200 to -67˚C) -89 to 32˚F (-67 to 0˚C) 32 to 271˚F (0 to 133˚C) 271 to 662˚F (133 to 370˚C)	+/- 1.5% +/- 1.8˚F +/- 1.8˚F +/- .75%	RED	BLUE	BLUE	Useable in oxidizing, reducing, or inert atmospheres as well as vacuum. Not subject to corrosion in moist atmospheres. Limits of error published for sub-zero temperature ranges.
E	-450 to 1800˚F	32 to 1600˚F	-328 to -274˚F (-200 to -170˚C) -274 to 32˚F (-170 to 0˚C) 32 to 644˚F (0 to 340˚C) 644 to 1652˚F (340 to 900˚C)	+/- 1% +/- 3.1˚F +/- 3.1˚F +/- 0.5%	RED	PURPLE	PURPLE	Recommended for continuously oxidizing or inert atmospheres. Sub-zero limits of error not established. Highest thermoelectric output of common calibrations.
N	32 to 4200˚F	32 to 2300˚F	32 to 559˚F (0 to 293˚C) 559 to 2300˚F (293 to 1260˚C) to ˚F (to ˚C) to ˚F (to ˚C)	+/- 4˚F +/- .75%	RED	ORANGE	ORANGE	Can be used in applications where Type K elements have shorter life and stability problems due to oxidation and the development of 'green rot'.
R	32 to 2700˚F	1000 to 2700˚F	32 to 1112˚F (0 to 600˚C) 1112 to 2642˚F (600 to 1450˚C)	+/- 2.7˚F +/- .25%	RED	BLACK	GREEN	Recommended for high temperature. Must be protected with non-metallic protection tube and ceramic insulators. Continued high temperature usages causes grain growth which can lead to mechanical failure. Negative calibration drift caused by Rhodium diffusion to pure leg as well as from Rhodium volatilization. Type R is used in industry; Type S in the laboratory.
S	32 to 2700˚F	1000 to 2700˚F	32 to 1112˚F (0 to 600˚C) 1112 to 2642˚F (600 to 1450˚C)	+/- 2.7˚F +/- .25%	RED	BLACK	GREEN	
B	1472 to 3100˚F	1600 to 3100˚F	1472 to 3092˚F (800 to 1700˚C)	+/- 0.5%	RED	GRAY	WHITE	Same as R & S but output is lower. Also less susceptible to grain growth and drift.

Technical Information

Control Systems Selection Guidelines *(cont'd.)*

Recommended Upper Temperatures for Protected Thermocouples					
Thermocouple Type	Sheath Diameters & Wire Sizes for Single Elements				Maximum Element Temperature
	1/16 OD	1/8 OD	3/16 OD	1/4 OD	
	28 Gauge	22 Gauge	19 Gauge	16 Gauge	
J	700˚F	700˚F	900˚F	900˚F	1400˚F
K	1600˚F	1600˚F	1800˚F	1800˚F	2300˚F
T	400˚F	400˚F	500˚F	500˚F	700˚F
E	800˚F	800˚F	1000˚F	1000˚F	1600˚F
N	2300˚F	2300˚F	1800˚F	1800˚F	2300˚F

Temperature or Process Controllers

Electric heat, while clean, efficient and manageable, can cause damage to product and / or equipment if the temperature is not known, and corrections applied as required. Best results will be obtained when the maximum and minimum allowable temperatures for a given process are known, and controls selected to achieve these results.

Types of Controllers:

Electronic Controllers

Electronic Controllers receive a signal from a thermocouple or RTD and determine how much heat is needed to control the process. These controllers can range from very simple dial controllers to complex multiloop PID controllers.

Advantages: Very accurate control, digital displays and flexibility for many applications

Disadvantage: More expensive than some mechanical controls.

Bulb & Capillary and Bi-Metal Thermostats

Mechanical thermostats depend on expanding liquids or metals to open or close contacts in response to temperature changes. Usually, no temperature is displayed, and a calibrated knob is provided on some models. In mechanical controllers, the sensor is part of the controller.

Advantages: Relatively inexpensive. Some bulb and capillary controls can switch large amounts of current for one or more poles (conductors). Easy to set up, just turn the knob for the desired temperature.

Disadvantages: On-off controls sometimes have a large differential or dead band. This is the difference in degrees between turn off and turn on. Your process variation will be greater than the dead band. Bulb and capillary controls do not fail safely. If the capillary tube with the fluid in it becomes pinched or broken, the thermostat will fail in a heat-on condition, which is a hazard. Bi-metal thermostats, which have no bulb or capillary, typically have smaller deadbands, and can control more closely. Some will not operate a contactor, which may be needed to switch the higher currents and voltages needed by the heater. They are often appropriate only for small 120-240V single-phase heaters. Temperature accuracy is inferior to electronic controllers.

Control Modes

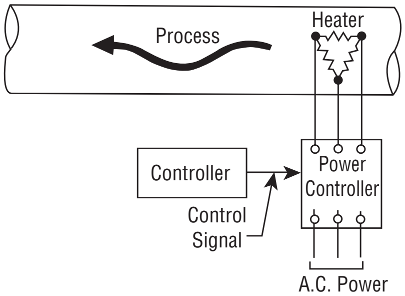
Manual: (switch or circuit breaker)
For some applications, such as water pipe freeze protection, circuit breakers are turned on in the Fall and off in the Spring.

Advantages: Low cost, easy operation.

Disadvantages: Possibility of not remembering to turn on equipment in the fall. Energy is wasted when equipment is on if it is not required. Consider an ambient temperature control to switch the equipment on if the temperature is below 40˚F.

Technical Information

Control Systems Selection Guidelines *(cont'd.)*



Open Loop Control System

Open Loop(Intensity or duty-cycle control):
Includes motor driven timers, infinite control bi-metal relays, and SCR controllers with knobs for setting power percentage. Open loop control does not use a sensor to determine the amount of heat needed. The control device is set to a specific percent output and switches the output on and off to approximate the percentage of available heater wattage. Typically used for radiant heat.

Advantages: Low cost, ease of operation.

Disadvantage: Does not compensate for variations in ambient temperatures or incoming product temperatures. Must, in many cases be reset, often after operator observation of poor process results.

On Off (bulb & capillary, bi-metal, or electronic) (See Figure 5)
The deadband (Hysteresis) represents an area about set point in which no control action takes place, and determines at what temperature the output switches ON and OFF. Narrow deadband settings give more accurate control but result in more frequent output switching, which can cause early failure of electromechanical contactors. On-Off control is available in electronic, bulb and capillary, and bi-metal controls.

Disadvantage: The control is only as accurate as the deadband. Large overshoots will occur with systems with significant lag.

Proportional
Proportional controls reduce the heat output gradually (within the Proportional Band), as the process approaches the set point.

Advantage: More accurate control than On-off control. In stable conditions (constant load), proportional control can maintain a specific temperature. Since they are electronic, with wired sensors, such as thermocouples, the control can sense an open sensor and shut down the process, resulting in a safer control system than mechanical on-off controls.

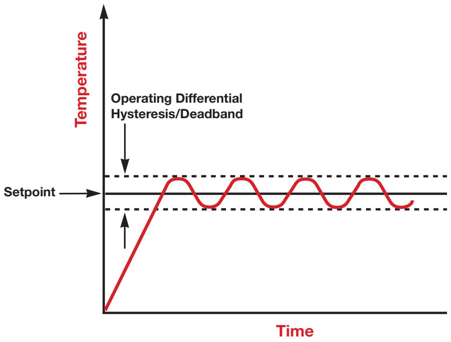


Figure 5

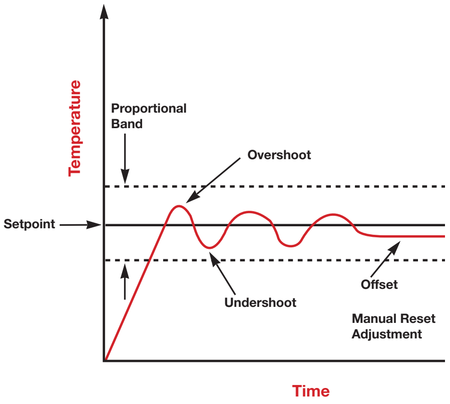


Figure 6

Disadvantage: Proportional controls work best on stable processes. They have trouble maintaining temperature during process upsets. Some proportional controls can switch significant loads with optional high current relays and solid state switching devices.

PID
PID (Proportional, Integral, and Derivative) controls, when properly set up (tuned) can manage most situations, including process upsets. Like a Proportional control, the heat output is gradually reduced while approaching set point, but also with the integral and derivative action can control processes with varying loads at set point. A wide variety of sensors and parameters ensure a good match of control to process. Many PID controllers have autotuning functions that automatically tune to the process.

Advantages: Good overall control. Since they are electronic, with wired sensors, such as thermocouples, the control can sense an open sensor and shut down the process, resulting in a safer control system than mechanical on-off control.

Disadvantages: More costly; more set-up required because of greater flexibilty. Requires external power controller to switch the load.

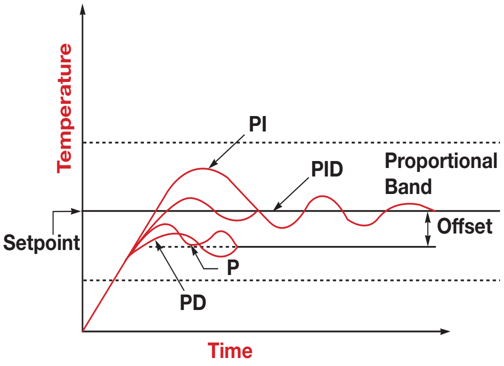


Figure 7

Overtemperature Controls(High Limit Controls):

(Bulb & capillary, electronic non-indicating, and electronic indicating).

Overtemperature controls provide a safety backup for the primary control and/or the heaters in case of a problem. The overtemperature controller's function is to protect the process or heater. In an overtemperature condition the overtemperature controller will shut down the process. The overtemperature controller cannot be cleared until the process cools and an operator manually resets the controller. It is important to use overtemperature controllers with a shutdown device such as a contactor to protect the heater process and personnel from damage or injury.

Technical Information

Control Systems Selection Guidelines *(cont'd.)*

Bulb & Capillary Overtemperature Controls have the same issues as mechanical temperature controls:
Advantages: they are inexpensive and can switch significant power. Most are easy to set up.

Disadvantages: Bulb and capillary controls do not fail safely. If the capillary tube with the fluid in it becomes pinched or broken, the control will not go into an alarm condition, which is a hazard. Knob shows nominal setting, but not process temperature.

Electronic Non-Indicating Overtemperature Controls:

Advantages: Inexpensive, easy set up. If power is lost to the controller or the sensor breaks, the overtemperature controller will go into alarm and shut down the process.

Disadvantages: Usually requires an external contactor to switch power. Knob has poor resolution for setting temperature, and there is no way to read process temperature.

Electronic Indicating Overtemperature Controls: are microprocessor based units with many sensor choices, and the ability to accurately view set point or process temperature.

Advantages: More set up accuracy, variable deadband. If power is lost to the controller or the sensor breaks, the overtemperature controller will go into alarm and shut down the process.

Disadvantages: Requires a contactor to switch the load. Set up more involved than for bulb and capillary units.

Level Controls. If a liquid is being heated, and the possibility exists for the level to fall to the point where the hot section of the heating element could be exposed to air, a level sensor is suggested to prevent damage to area, heater and/or liquid. See the catalog for selection based on your fluid type. Level control should be wired so heater turns off if liquid falls below acceptable level.

Environmental and Safety Considerations:
Process controls, overtemperature controls, and accessories must be selected with the surrounding area in mind. Wet, dry, explosion hazard areas must be considered, as well as the ambient temperature range the equipment will see. Mechanical controls should not be exposed to temperatures above the control temperature range. Electronic controls are designed to operate above 32˚F, and below a stated maximum, usually 120 or 140˚F. See specific control for ambient temperature range.

Power Controls

For small loads (less than 20 amps) some bulb and capillary and electronic controllers can switch the heater directly. For larger loads it is necessary to use an external power controller. There are various mechanical and solid state power controllers available.

Types of Power Controls

Mechanical Contactors

Mechanical contactors are similar to motor starters. They are capable of switching large amounts of power on an infrequent basis. If turned on and off at a fast rate (more than 1 or 2 times a minute), mechanical wear and contact erosion will require frequent replacement.

Advantages: Low cost. High switching currents. They do not produce much heat from their operation.

Disadvantages: Contactors are subject to mechanical wear, and produce electrical and mechanical noise.

Mercury Displacement Contactors

Mercury displacement contactors (or mercury contactors) are similar in operation to above mechanical contactors, except mercury is made to move up and down a sealed tube by an external electromagnet, which pulls down a steel core when the coil is energized.

Advantages: Little mechanical noise, long life, with faster on and off cycles (every 10 seconds) than regular mechanical contactors.

Disadvantages: Contains mercury, a hazardous substance, not permitted in some plants. Mercury tubes may rupture during severe over current conditions, releasing the mercury. (Fast semi-conductor fuses minimize this possibility).

Snubbers
To minimize electrical noise, snubbers should be connected across each contactor coil minimizing arcing of control relay contacts. A Snubber is an electronic circuit, which absorbs the inductive kick back of the contactor coil when it turns off.

Environmental and Safety Considerations:
Arcing contactor contacts may ignite flammable vapors. Mercury may be released from mercury contactors.

Technical Information

Control Systems Selection Guidelines *(cont'd.)*

SCR's

SCRs (Silicon Controlled Rectifiers) are devices used to switch power. Since SCRs are solid state devices with no mechanical moving parts, they are able to switch current quickly without wear. Some SCR devices can switch up to 600VAC at 600 amps. With this switching capability they are used to precisely control single or three phase heater loads. Many different "firing packages" are available to achieve desired results with varying load types and related conditions. "Zero-crossover firing" switches power at the zero voltage or the sine wave almost eliminating EMI and RFI. "Phase-Angle firing" switches anywhere in the sine wave and although it is electrically noisy, it is required for some loads i.e. tungsten, transformer driven load.

SCRs have two major disadvantages over mechanical contactors. 1) SCRs tend to fail shorted (full on). A mechanical disconnect device and overtemperature controller are strongly recommended. SCRs CANNOT BE USED AS A SHUT DOWN DEVICE. 2) SCRs generate heat when current is passed through them (1.5 watts per amp or per leg). For example, an SCR switching a 100Amp load, with 2 legs of a three phase design will generate approximately 300Watts of heat. It is important to include cooling or ventilation in designs using SCRs.

SCR power controllers come in many shapes and sizes. Solid State Relays are the simplest SCR devices. These are generally single phase, low current devices with few special features. More sophisticated and higher amperage SCR power controllers, sometimes called Power Packs, have more features and capabilities.

Zero Crossover Firing

Zero-crossover fired SCRs turn on at the zero voltage point of the sine wave. Switching at zero volts means no current is flowing when the switching occurs and therefore little conducted and/or radiated electrical noise is produced. This helps prevent problems with nearby computers and other instrumentation, which may be noise sensitive. Types of zero crossover control are:

- On-Off
- Time Proportional
- DOT

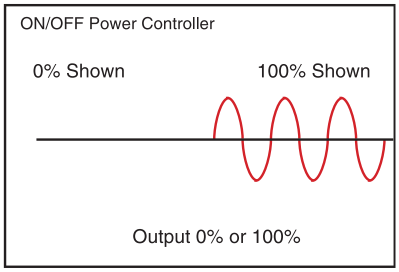


Figure 8

On–Off Zero-Crossover Control receives a signal from a remote device to turn on or off. Generally a temperature controller will cycle it's output to approximate a percent output. For example: for a 50% output the controller will turn on the SCR for 1/2 second and turn it off for 1/2 second. The signal from the controller can be a pulsed dc voltage, or a relay contact input.

Time Proportional Zero-Crossover Control receives an analog signal (i.e. 4-20mA) from a remote controller or other device. The SCRs time-proportional firing package takes the 4-20mA signal and converts it into a ON and OFF time based on the cycle time. For example, the cycle time is 2 seconds, the signal received is 50%(12mA), the firing package will have the SCR turn on for 1 second and off for one second.

DOT (demand oriented transfer) zero-crossover control

The SCRs DOT firing package takes the 4-20mA signal from a remote controller. Demand Oriented Transfer (DOT) is a zero-crossover SCR which varies the on-off time to the smallest possible time base to provide superior resolution and minimum power supply disturbances. For example, a 50% power output can be one cycle on and one off. Considering the incoming supply is 60 cycles per second, the SCR can be turning on and off 30 times a second. DOT firing is the most accurate Zero-Crossover firing method. Zero-Crossover firing also ensures low electrical noise.

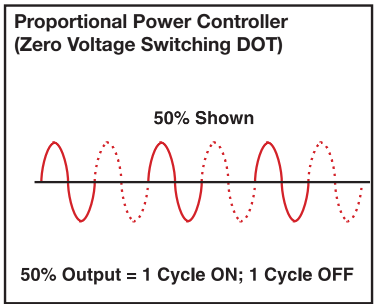


Figure 9

Phase Angle

A phase angle control splits each half cycle into a percentage needed for the instantaneous load requirements. Phase angle firing is required for tungsten and transformer loads.

Advantages: extremely tight control.

Disadvantages: Electrical noise and power line harmonics are produced during operation. With these noise problems, even though phase angle control is tighter than zero-crossover control it is usually only used when required by the load type.

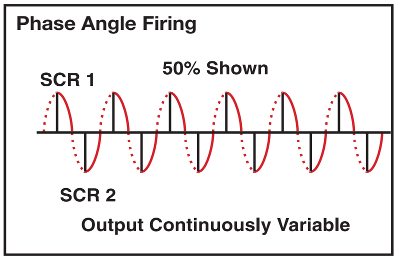


Figure 10

Technical Information

Control Systems Selection Guidelines *(cont'd.)*

Three Phase Power Control Using SCRs

2 leg vs. 3 leg – “Legs” refers to the number of lines switched in a 3-phase SCR circuit. “Two legs” means 2 of the three lines are switched, and the third is passed through un-switched (hot).

Advantage: 2 leg is cheaper than 3 leg switching, since only 2 sets of SCR’s are needed, not 3. Only 2/3 as much heat is produced by the SCR’s in a 2 leg vs. a 3-leg system. Two leg switching can only be used with zero-crossover SCRs and on Delta or 3 wire Wye loads.

3 leg for 3 phase loads – 3 leg control is required for any 4 wire Wye load and for any 3-phase angle fired applications.

Environmental and Safety Considerations:
Power controls, and accessories must be selected with the surrounding area in mind. Wet, dry, and explosion hazard areas must be considered, as well as the ambient temperature range the equipment will operate in. SCR controls are designed to operate above 32˚F, and below a stated maximum, usually 100 to 120˚F. See specific SCR for allowable ambient. Heat produced by the SCR’s must be removed. This is usually done with ventilation, fans, air conditioners or heat sinks mounted on the outside of the enclosure. Even if the SCR has a built-in fan, ample air changes in the panel must be provided, perhaps by an additional fan, to keep inside of panel below maximum allowable ambient for the components inside, for the highest expected external ambient.

Choosing a Power Control

Electrical Considerations

Contactors must be selected for voltage and current of load(s). If you have three 3 phase, 30 Amp loads, for example, 3 small contactors may take up less space than one large contactor, and would be more cost effective.

SCR’s should be selected / specified based on the voltage, total current of the load(s) and the number phases. For a 3-phase delta circuit a 2-leg unit can be used, for 3-phase 4 wire circuits, or phase-angle control, 3 leg SCR’s are required. Be sure to use I^2T fuses (fast blow) to protect the SCR’s.

Environmental and Safety Considerations:
Power controls and accessories must be selected with the surrounding area in mind. Wet, dry, explosion hazard areas must be considered, as well as the ambient temperature range the equipment will experience. Panels generally require internal heaters, if the ambient is below 32˚F. In addition, the maximum ambient should be considered and taken into account. This is particularly important for SCR panels, since the SCR’s generate heat, which must be removed during operation. Panels should not be mounted where they will receive direct sunlight.

Power Control Panels

Power Control Panels are assembled systems which combine temperature control, overtemperature control, contactors, SCRs and other components into a prewired complete control system.

Stock Panels

Chromalox has a good selection of “off the shelf” stock Contactor, SCR and Heat Trace panels. Features include, NEMA 4X Fiberglas® enclosure, contactors of 40, 75, or 90 Amp rating. Optional temperature controls, overtemperature controls and disconnects are also available.

Standard Design Panels

Chromalox has pre-designed panels of several series, both SCR and contactor, with NEMA 1, 4, 4X, and 7 ratings. Many choices of voltages, currents, branch circuit fusing and controls are offered. Consideration is given to heat dissipation, environments and safety requirements.

Custom Design Panels

Chromalox is ready to design and manufacture your custom panel as a variation of one or our standard panels or full custom from scratch. Many additional features are available. We can incorporate motor starter relays for pumps and fans, as well as use specific brand controls to meet plant specifications. Chromalox has a UL approved panel-shop and can also make panels to military specifications. Chromalox’ instrument, control and panel shops are ISO-9001.

Choosing a Panel

Panel should be selected/specified based on the voltage, current, and number of circuits of the load(s). Panel must be compatible with the area classification (ex. NEMA 4) where it is to be located.

Loads, Circuit Protection

The National Electrical Code (NEC) requires load circuit protection for all circuits and branch circuits. HVAC heating applications further require that all sub circuits not exceed 48 amps.

Advantages: Keeps wire sizes reasonable, and allows for more reliable operation. If one circuit shorts, the others can usually continue to operate, if fused separately.

Technical Information

Control Systems Selection Guidelines *(cont'd.)*

Wiring Issues
Chromalox panels are compliant with the NEC. The installer is responsible for applying NEC and all local codes. The connection to the heater may require special high temperature wire at least within several feet of the heater, to prevent wire insulation damage, and / or conductor oxidation.

Environmental and Safety Considerations:
Panels and accessories must be selected with the surrounding area in mind. Wet, dry, explosion hazard areas must be considered, as well as the ambient temperature range the equipment will operate in. Panels generally require an internal heater, if the ambient is below 32˚F. In addition, the maximum ambient should be considered and taken into account. This is particularly important for SCR panels, since the SCR's generate heat during operation. Panels should never be mounted where they will receive direct sunlight. Outdoor installations require shading.

Building a Panel

Choosing Controllers and Power Controls
Temperature controls, overtemperature controls, and power controls must be chosen based on process temperature range, process speed, area classification, ambient temperature, (minimum and maximum), voltage and current.

Heat and Cold Management
While heat is the usual panel load, it is the enemy inside of a panel. This is especially true for SCR panels. Fans must be provided to remove heat generated, and ensure that the temperature inside the panel does not exceed the maximum operating ambient for the power controls and other components. For wet, dusty, or explosion areas, consider mounting the panel in a clean, dry control room away from contaminants. There are different standard models of Chromalox panels that are built with these considerations. All include specifications of maximum ambient temperature outside the enclosure.

Layout Considerations
Panel layout must follow NEC and local codes. Ample room must be provided for all components, and bend radii of the wiring. Door mounted components must clear sub-panel mounted components. Wiring must allow for easy door opening for access. A disconnect should be provided to permit safe access to panel components for servicing. All Chromalox Panels meet NEC codes.

Environmental and Safety Considerations:
Panels and accessories must be selected with the surrounding area in mind. Wet, dry, explosion hazard areas must be considered, as well as the ambient temperature range the equipment will operate in. Panels generally require an internal heater if the ambient is below 32˚F. In addition, the maximum ambient should be considered and taken into account. This is particularly important for SCR panels, since the SCR's generate heat during operation. Panels should not be mounted where they will receive direct sunlight.

Technical Information

Thermal System Glossary

A

Absolute Zero – The lowest theoretical temperature. At absolute zero, a body would have no molecular motion of heat energy. Absolute zero is the zero point on the Rankine and Kelvin scale. (-273.15˚C or-459.67˚F)

Accuracy
Calibration Accuracy – the potential error of a device compared to a physical constant or agency standard.
Control Accuracy – maintaining a process at the desired setting. The errors or combination of errors in the entire system including the sensor, control, power, load and design inefficiencies effect control accuracy.
Display Accuracy – the amount of potential error between a measured value and the control's displayed value.
Set Point Accuracy – the potential error between a measured value and the control setting.

Address – for digital communication between host computer and control, is a numerical value, typically between 1 and 255. The same address must be entered into both the computer program and the specific control to be addressed, or communicated with.

Alarm – a control condition or function, indicating that the process is at a predetermined amount above and/or below the set point.

Alarm relay options – normally energized (relay energized when not in alarm) normally de-energized (relay not energized unless in alarm). Latching means a reset button must be pushed when the temperature drops below the alarm setting plus dead band.

Alarm Type – typical choices for PID controls are: disabled, high, low, + deviation, -deviation, +/- deviation., and event (for ramp soak units.)

Algorithm – a set of rules with a finite number of steps for solving a problem.

Alternating Current (AC) – an electrical power system where the voltage reverses, alternating negative and positive. Typical frequency is 50 or 60 Hz. (cycles per second)

Ambient Compensation – the ability of an instrument to compensate for changes in the ambient temperature so that the changes do not effect control accuracy.

Ambient Temperature – the temperature of the immediate surroundings in which equipment is to operate.

AWG (American Wire Gauge) – also known as B & S wire gauge. Standard system to specify the diameter of wires for both power and control circuits. The larger the gauge number, the smaller the wire diameter.

Ampere (amp) – the rate of flow of current in a circuit.

Analog Indication – a meter with graduated scale and a pointer that moves to indicate process condition.

Analog Output – a voltage or current signal that is a continuous function of the measured parameter.

Analog Set Point – potentiometer adjustment of the control setting

Anneal - To relieve stress in a metal or glass material by heating to just below its melting point, then gradually cooling to ambient temperature. Annealing lowers tensile strength while increasing flexibility. Tubular heaters are annealed prior to forming.

ANSI – American National Standards Institute

Anti-reset Windup – a feature in 3 mode (PID) controls which prevents the integral (automatic rest) circuit from functioning when the temperature is outside the proportional band.

ASME – American Society of Mechanical Engineers.

ASTM – American Society for Testing and Materials.

Atmospheric Pressure (Standard) – Pressure exerted by the earth's atmosphere on the objects within. Measured at 60˚F (15˚C), at sea level, standard atmospheric pressure is 14.7 psia.

Automatic Reset (Integral) – the integral function of a control that automatically compensates for the difference between the set point and the actual process temperature. A signal moves the proportioning band up or down to correct for the droop or offset error.

Automatic Tuning (of control parameters) – a control that calculates the optimum PID parameters with a built-in software algorithm to eliminate manual tuning efforts.

Auxiliary Output – additional outputs for control of functions other than the primary control output, such as lights, buzzers, horns or gas purges that are triggered by the control alarm function.

Auxiliary Setpoint – an alternate set point on some PID controls, which can be selected from a button or external signal.

AWG – American Wire Gauge.

B

Band and Nozzle Heaters – component heaters designed to heat cylindrical objects such as plastic extruders. A variety of sizes and constructions are available.

Bandwidth – the total temperature variation measured at some point in the system, normally the process.

Baud Rate – In serial communications, the rate of information transfer in bits per second. Must be set for the same value in the controller and the host computer program. Typical values are 1200, 2400, 4800, 9600, and 19200. The control, computer and wiring must be able to operate at the baud rate selected.

Bend Radius (minimum) – the minimum radius for bending a wire, heating element or heat trace cable, without damage.

Blackbody – a theoretical object that radiates the maximum amount of energy at a given temperature and absorbs all energy incident upon it.

Braid – a flexible woven covering, usually of metal wire, covering an insulated wire to provide a ground path (or shield) or to protect from mechanical damage.

Technical Information

Thermal System Glossary *(cont'd.)*

Boiling Point – the temperature at which a substance in the liquid state transforms to the gaseous state. Commonly refers to the boiling point of water (100˚C or 212˚F at sea level).

BTU – British Thermal Unit; the amount of thermal energy required to raise one pound of water, 1˚F .

Bulb & Capillary – refers to thermostat construction which has a bulb filled with a fluid in the process. The increasing heat forces the fluid through a narrow tube into a bellows. The bellows actuates a snap switch, at a temperature determined by the knob setting which moves the switch toward or away from the bellows.

Bulkhead Threaded Fittings – available on tubular heaters, factory brazed, to allow heaters to be mounted through the wall of a tank or duct, etc.

Bumpless Transfer – The smooth, automatic transition from automatic control (closed loop) to manual control (open Loop). The control output is maintained during the transfer.

Burst Firing – a fast cycling control output, typically 3-32VDC, used in conjunction with a solid state relay.

C

Calibration – the process of adjusting an instrument so that the indication is accurate compared to the actual value.

Calorie – the amount of thermal energy required to raise one gram of water 1˚C at 15˚C

Cartridge and Immersion Temperature Controllers – are mechanical Thermostats with operation based on the difference of expansion of different metals.

Cartridge Heaters – cylindrical heaters with leads exiting one end. Most often inserted in drilled holes in platens and molds to heat blocks of metal. A variety of standard diameters, lengths and wattages are available, as well as special lengths, electrical ratings, and lead wire options.

Cascade – Control function where the output of one control loop provides the set point for a second loop, which determines the control action.

CE – A mark that designates compliance with European Union (EU) requirements for products sold in Europe

Celsius – (Centigrade) a temperature scale with 0˚C defined as the ice point and 100˚C as the boiling point of water at sea level.

Ceramic Beads – beads of ceramic material, with various hole sizes, intended to insulate bare high temperature wire, to prevent short circuits.

Ceramic Fiber – a light weight, low density fiber, typically used as a high temperature insulation or a refractory

Ceramic Post Terminal Insulators – used to cover the terminals of common strip heaters to prevent personnel contact with electrical hazards. Sold in pairs.

cfm – the volumetric flow rate of a liquid or gas in cubic feet per minute.

Chatter – the rapid cycling of a relay due to too narrow a bandwidth in the control.

Circuit – a complete or partial path over which current may flow.

Circulation Heaters – heaters for fluids or gasses consisting of an insulated pipe body with an immersion heater inside. Various sheath and pipe body materials are offered to heat a variety of material to a range of temperatures. Mechanical thermostats are included on some models. Options include mechanical or electrical controls, built-in sensors, baffles, and ASME design and certification. Complete skid mounted systems with panels are also available.

Closed Loop Control – a control system in which process temperature changes are detected by a sensor. The feedback from the sensor allows the control to make adjustments for accurate system regulation.

Cold Junction Compensation – a temperature sensitive device that prevents changes in the ambient temperature from affecting the cold junction of a thermocouple.

Cold Length – the distance from the end of the sheath to the heated section of a tubular or other similar heater.

Comfort Heaters – heaters, usually for the heating of areas to maintain comfort of the occupants. Generally not for use in areas above 100˚F. A wide variety of types (convection and fan forced) are available for use in ordinary, corrosive, and explosion hazard areas.

Common Mode Line Filter – a device to filter noise signals on both power lines with respect to ground.

Common Mode Rejection Ratio – the ability of an instrument to reject interference from a common voltage at the input terminals with relation to ground. Expressed in dB (decibels).

Compression Fittings – bulkhead fittings designed for customer installation on round tubular heaters, to allow heaters to be mounted through the wall of a tank, duct, etc.

Conduction – the transfer of heat from one material at a given temperature to another material at a lower temperature, while in direct contact with each other.

Conductivity – the ability of heat or electricity to flow through a material.

Constant Wattage – refers to a type of heat trace cable having a constant wattage output regardless of the surrounding temperature.

Continuity Check – A test that determines whether current can flow throughout the length of a circuit.

Control Loop – the basic control loop of any automatic control system consists of:
1) variable (process)
2) sensor
3) error detector (of control)
4) control
5) final control element (relay, SSR, SCR)
6) temperature indication

Technical Information

Thermal System Glossary *(cont'd.)*

Control Mode – the method in which the control restores the system temperature to set point. On/Off, proportioning, and PID are the most common control modes.

Control Type – options are direct acting (cooling) and reverse acting (heating).

Convection – the transfer of heat from a source or higher temperature area in a gas or liquid by the movement and mixing of the masses.

CSA – abbreviation for third party testing and approval agency, Canadian Standards Association

C-UL – this is an acceptance of UL (Underwriter's Laboratory) approval of a product. Often accepted by customers who would normally require CSA approval.

CPS – Cycles per Second (See Hertz).

Current – measured in amperes (A), is the flow of electricity. One ampere is one coulomb per second.

Current Limiting – a means to limit the current delivered to a load by a power control device, usually an SCR.

Current Proportioning – a 4-20 milliamp (typical) current output which provides a current proportional to the amount of control required.

Current Transformer – a transformer, usually toroidal (doughnut) shaped, designed to accommodate an electrical conductor, and provide a reduced, but linear output at a lower current, for instrument use. Typically specified by ratio i. e. 100:1

Cycle Rate (or Cycle Time) – in a time proportioning control, the period (usually in seconds) of time that is required to complete one on/off cycle once temperature has settled at the center of the proportioning band.

D

Data Logging – Recording a process variable over an extended period of time.

Dead Band (differential) – is the difference in degrees between temperature control turn on an turn off. This parameter is for on-off controls. It also applies to overtemperature controls.

Default Parameters – The programming instructions permanently written in microprocessor software.

Definite Purpose Magnetic Contactor – similar to a motor starter relay, for use with on-off controllers for slow processes. Available with optional enclosures for general, wet, and explosion proof areas.

Density – mass per unit of volume, such as lbs./cu.ft.

Derivative – (See Rate)

Deviation – the difference between the selected value and the actual value.

Deviation Alarm – an offset value that follows the set point. If the set point is 300˚F and the Deviation Alarm value is +20˚F (or 320˚F), then the set point is changed to 350˚F, the Deviation Value alarm would be 350˚F plus 20˚F (or 370˚F). See Process Alarm.

Deviation Meter – the display of process temperature on meter that indicates difference of or deviation of the process temperature from the set point.

di/dt – the rate of change of current vs. time. Filtering on large SCR units may be necessary to prevent damage from large current changes in small time periods

Dielectric – an electrical insulator - a material with low electrical conductivity.

Dielectric Strength – an amount of voltage that an insulating material can withstand before an electrical breakdown occurs.

Differential – in an on/off control, the temperature difference expressed in degrees between where the control switches off and the control switches on.

Differential Mode Line Filter – a device to filter noise signals between two power lines.

Digital Indication – the actual process temperature in indicated by LED or LCD display.

Digital Set Point – the desired temperature value is set by means of up-down pushbuttons or pushwheel switch.

DIN – Deutsche Industrial Norms, a German agency that sets engineering standards. Control panel hole size cutouts are typically based on DIN dimensions

Diode – A device that allows current to flow in only one direction.

Direct Current (DC) – an electric current flowing in one direction.

Disconnect – a control panel mounted main switch, which provides a means to turn off power in the panel before opening the door for servicing. Most disconnects do not provide overcurrent protection. This must be provided upstream using fuses or circuit breakers.

Dishwasher Heaters – immersion heaters with terminal housing and built-in controls, designed for use in commercial dishwashers

DOT (Demand Oriented Transfer) – an SCR power control system using the smallest time base possible. For example, 25% output would be 1 cycle on, and 3 cycles off.

Drift – a change in a value over a long period due to changes in factors such as ambient temperature, time or line voltage.

Droop – in time proportioning controls, the difference in temperature between the set point and where the system temperature stabilizes. Corrected by automatic or manual reset.

Drum Heaters – flexible heaters designed to heat or maintain the temperature of standard 5, 16, 30 and 55 gallon drums. A selection of ratings are available, some with thermostats.

Dry Well Heater – a heater designed to be installed in a dry area, usually a pipe, to heat the pipe, with the ultimate purpose of heating liquid surrounding the pipe.

Technical Information

Thermal System Glossary *(cont'd.)*

Dual Output – the primary control output will regulate the process temperature. A secondary control output will be utilized for process cooling or as an alarm.

Duty Cycle – the ratio of on time to on time plus off time, expressed as a percentage.

dv/dt transient protection – filtering to limit voltage vs. time presented to an SCR. Helps protect SCR's against transient voltages.

E

Efficiency – the amount of useful output versus energy input, expressed as a percentage.

Electric Stud Heater – a long cylindrical heater designed to be inserted into the hollow bolts of large machinery to obtain "shrink fit tightness" when the bolts cool.

Electromagnetic Interference (EMI) – electrical and magnetic "noise" than can be generated when switching AC power. EMI can interfere with the operation of microprocessor based controls.

Element Clamps – cast iron clamps are offered to clamp strip and ring heaters to surfaces for conduction heating of tanks, etc.

Emissivity – The ratio of radiant energy emitted from a surface compared to the radiant energy emitted from a black body at the same temperature.

Endothermic – a process is endothermic when it absorbs heat.

Enthalpy – the sum of the internal energy of a body and the product of its volume multiplied by the pressure used to evaluate the energy change occurring when a vapor or gas is heated. Expressed in units of Btu/lb. or Joules/gram.

Error – the difference between the correct value and the reading or display value.

Exothermic – a process is exothermic when it generates heat.

Explosion Proof Strip Heater – used to heat by conduction in areas with explosion hazards.

Explosion Proof Terminal Housing (or Enclosure) – an enclosure, housing, or panel which will contain a internal gas explosion. This prevents an explosion from setting off surrounding area. Housing contents must not produce surface temperature which would ignite flammable gases or vapors in the vicinity.

Extension Wire – wire intended to connect a sensor (typically a thermocouple or RTD) to a panel or control. Thermocouple wire must be same type as TC (J for J). RTD wire may be copper.

External Interlock – provided on most Chromalox panels, the interlock is a jumper, which turns off the load when interrupted. Typically connected to a flow or pressure switch for moving systems to protect against a no flow condition.

Event – a programmable On/Off output used to signal peripheral equipment or a process.

F

Fahrenheit – a temperature scale with 32°F defined as the ice point and 212°F as the boiling point of water at sea level.

Flanged Immersion Heaters – immersion heaters with mounting flanges (ANSI standard and others). Most offer a choice of terminal housings for various environments. Optional sheath thermocouples are also available.

Flexible Heaters – available in many standard sizes and ratings, most are constructed of silicone rubber, with internal winding. Specials with accessories such as thermostats, cords and plugs are available, as well as unique shapes.

Flow Rate – speed or velocity of fluid movement.

FM (Factory Mutual Research Corporation) – a third party approval agency, which tests and approves equipment for service in various areas and conditions.

Form A Relay – Single pole, single throw relay with Normally Open (NO) and common contacts. When coil is energized, the contacts will close.

Form B Relay – Single pole, single throw relay with Normally Closed (NC) and common contacts. Contacts are open when coil is energized.

Form C Relay – Single pole, double throw relay with Normally Open (NO), Normally Closed (NC) and common contacts. Can be selected as Form A or Form B contact.

fpm – flow velocity in feet per minute.

fps – flow velocity in feet per second.

Freezing Point – the temperature where a material changes from a liquid to a solid.

Frequency – the number of event occurrences or cycles over a specified period of time.

Fuse – A device that interrupts power in a circuit when an overload occurs.

Fuzzy Logic – An artificial intelligence technique that allows control decisions to be made upon approximate or incomplete information. It is a continuous decision making function that can prevent initial overshoot and set point differentials.

G

GFCI – (Ground Fault Circuit Interrupter) – an electronic circuit which monitors the current flowing from a conductor to a ground reference. When the current exceeds a predetermined value, the GFCI shuts the circuit down.

GIGA – the prefix for one billion (G).

gph – the volumetric flow rate in gallons per hour.

Technical Information

Thermal System Glossary *(cont'd.)*

gpm – the volumetric flow rate in gallons per minute.

Ground – the electrical line having the same potential as the surrounding earth; the negative side of a DC power supply; the reference point for an electrical system.

Grounded Junction – A thermocouple junction in which the sheath and conductors are welded together forming a completely sealed integrated junction.

H

Heat – thermal energy expressed in Calories, Btu's or Joules.

Heat Balance – proper sizing of the heat source to the requirements of the system (including heat losses).

Heat Exchangers – metal tubes or plastic coils designed to heat or cool solutions by immersion, with a fluid (or steam) circulating through the coil to obtain the desired effect.

Heat of Fusion – the amount of energy required to change one pound of a material from a solid to a liquid without an increase in temperature. Expressed in Btu/lb.

Heat of Vaporization – the amount of energy required to change one pound of a material from a liquid to a vapor without an increase in temperature. Expressed in Btu/lb.

Heat Offset – for some PID controllers; allows the creation of a dead area where neither heat nor cold is on, to prevent the process from oscillating between heat and cool. Saves energy.

Heat Sink – in power control, an array of plates or fins, usually aluminum, which conducts heat away from the power control devices (SCR's) and dissipates the heat by free or forced convection.

Heat Tracing – heat applied to pipes or tanks, to replace heat lost through the insulation to the ambient.

Heat Transfer – a process of thermal energy flowing from one body to another.
1) Conduction: the transfer of heat from one particle of matter to another.
2) Convection: the transfer of heat from one part of a particle to another by the mixing of the warmer particles with the cooler.
3) Radiant: the transfer of heat from one body to another as the result of the bodies emitting and absorbing radiation energy.

Heat Transfer and Release Coating – a compound designed to be applied between heaters and the surfaces being heated to improve heat transfer. Also makes cartridge heaters easier to remove from drilled holes.

Heat Transfer Fluid Vaporizer – a vaporizer for heat transfer fluids, to obtain improved process heat transfer by recovery of the heat of vaporization.

Heat Transfer Medium – a gas, liquid or solid through which heat flows from the heat source to the work.

Heat Transfer Systems – consist of circulation heater(s), pump, control panel and related items, ready to connect to your service and process. Oil and water systems are available, in many sizes with a host of features and accessories.

Helically Coiled Resistance Wire – a coil of Nichrome wire, wound in a helix, which is the resistance winding of the heater.

Hertz – units of expression for frequency, measured in cycles per second.

High Temperature Wire – special wire with high temperature insulation and nickel or nickel plated copper conductor. Can withstand higher temperatures than plastic insulated copper conductor wire used for general connections. Do not use tin plated copper lugs on high temp wire. They will oxidize and fail. High temperature terminations require special nickel or stainless steel lugs, if lugs are used.

Hi-Pot Test – the application of a high voltage to an electrical conductor to test the surrounding insulation.

Hopper Heaters – modular heaters, consisting of tubular heating elements mounted to a metal plate, for attachment to hoppers. These are used to keep the walls above a critical temperature to prevent contents from sticking to or attacking the hopper.

Humidity Transmitter – an electronic device which provides a 4-20 mA signal based on the relative humidity sensed by the probe.

Hysteresis – the temperature sensitivity designed into the on/off control action between the on and off switching points. Expressed in percentage of control range. Also known as dead band.

I

Ice Point – the temperature where pure water freezes (0˚C or 32˚F).

Immersion Heaters – heating elements designed to heat a fluid or gas by direct contact.

Impedance – the total opposition in a circuit to the flow of alternating current. Measured in ohms and represented by "Z".

Infrared – or radiation is the exchange of energy by electromagnetic waves. The infrared spectrum extends from the deep red end of the visible spectrum to the microwave region of the radio spectrum, The portion adjacent to the visible spectrum is of importance to heating. Radiant heat transfer can be very efficient in directing energy from the heat source to an object.

Insulation, Electrical – a substance which surrounds an electrical conductor, to prevent current from flowing to or leaking to ground or to other conductors.

Insulation Resistance – is the resistance of an insulator to current flow from a conductor (typically a heating element winding) to ground (the sheath). Usually measured by the application of a voltage, and measuring the resulting current. The resultant resistance, which is expressed in ohms, is calculated by the formula: R= V / I.

Technical Information

Thermal System Glossary *(cont'd.)*

Insulation, Thermal – a material which reduces heat flow from heated areas or objects to colder objects to conserve energy improve performance, or prevent operator contact with hot objects.

Input Scaling – allows PID control to be adjusted to display inputs from transmitters (i.e. humidity), in appropriate engineering units.

Integral – (See Automatic Reset).

Intrinsic Safety Barriers – devices that limit current voltage and total energy delivered to a sensor or other instrument located in a hazardous area.

Intrinsically Safe Equipment and Wiring – products that are not capable of releasing sufficient energy in a circuit to ignite a flammable atmosphere in a hazardous area.

Isothermal – a process or area that maintains a constant temperature.

J

Joule – the basic unit of thermal energy. 1 Joule equals 1 ampere passed through a resistance of 1 ohm for 1 second.

Junction – A thermocouple junction is the point at which two alloys are joined. A typical thermocouple circuit would have a measuring and a reference junction.

K

Kelvin – the unit of absolute or thermodynamic temperature scale. Zero Kelvin is absolute zero, where all molecular activity stops. No ° symbol is used. 0˚C = 273.15K; 100˚C = 373.15K.

Kilo – the metric prefix for one thousand (K).

Kilowatt (kw) – 1000 watts or 3412 Btu per hour.

Kilowatt Hour – electrical unit of energy expended by one kilowatt in one hour.

L

Lag – the time delay from application of heat until the process reaches temperature or the delay in a controller responding to a temperature change.

Least Significant Digit – The digit farthest to the right in a display.

Light Emitting Diode (LED) – a solid state device which produces light from the flow of electric current through a semiconductor. These are individual indicating lights or segmented readouts used to display temperature.

Linearity – the compliance of an instrument's response to a straight line.

Liquid Level Control – detects liquid level below a reference depth. Can be used for replenishment or to turn off a heater to prevent damage.

Load – the electrical demand of a process expressed as wattage, amps or resistance (ohms).

M

Manual Reset – the adjustment on a proportional control which shifts the proportioning band in relation to the set point to eliminate droop or offset errors.

Mass Flow Rate – weight of a substance flowing per unit of time past a specific cross-sectional area within a system.

Maximum Allowable Load Resistance – the maximum resistance (in ohms) into which a control can deliver specified current. Usually specified for 4–20mA outputs, and is limited by internal control supply voltage.

Mean Temperature – the maximum and minimum temperature average of a process at equilibrium.

Measuring Junction – the thermocouple junction at the point of measurement in the process.

Mechanical Relay – an electromechanical device that completes or breaks a circuit by closing or opening electrical contacts.

Mega – the metric prefix for one million (M)

Mercury Contactor (Mercury Displacement Relay) – a mechanical relay with mercury as the current carrying conductor. They are faster, quieter, and last longer than conventional mechanical contactors. Contains mercury, a hazardous substance, not permitted in some plants.

MI Cable (Mineral Insulated Cable) – refers to metal sheath heat trace cable, having internal magnesium oxide insulation between the conductor(s) and the sheath. Specially suited for high temperature operation, and is mechanically rugged. All MI cables are made to order.

Micro – The metric prefix for one millionth Microamp (one millionth of an amp).

Micron – (one millionth of a meter).

Microprocessor – The central processing unit (CPU) that performs the logic operations in a micro-computer system. The microprocessor in a process or instrument control decodes instructions from the stored program, performs algorithmic and logic functions, and produces signals and commands.

Milli – The metric prefix for one thousandth

Milliamp – (one thousandth of an amp).

Millivolt – (one thousandth of a volt)

Technical Information

Thermal System Glossary *(cont'd.)*

Moisture Resistant Terminal Housing – a terminal housing designed to meet the requirements of NEMA 4. Chromalox types E2 and E4 meet these requirements.

MOV Protection – SCR protection provided by a Metal Oxide Varistor (MOV), which clamps voltages at limits to stay below critical SCR failure values.

N

NEC (National Electrical Code) – regulations and specifications for wiring as published by the National Fire Protection Association, Inc.

NEMA – National Electrical Manufacturer's Association

Noise – undesirable electrical interference on the signal wires.

Noise Suppression – a device used to reduce electrical interference.

Normal Mode Rejection Ratio – the ability of an instrument to reject interference of the line frequency (50-60Hz) across the input terminals.

NPT – National Pipe Thread

O

OCE (Open Coil Element) – heaters designed to be installed in 2 or 3 inch customer- supplied threaded schedule 40 dry well pipes to heat liquids with the heat transferred through the pipe walls. Provides low watt density on the pipe for viscous fluids, and allows for heater replacement without draining the tank. Available terminal housings provide easy connections to heater with high temperature wire. Not for use in explosion hazard areas.

Offset – the difference in temperature between the set point and the actual process temperature.

OHM – the unit of electric resistance.

On-Off – a control whose action is full on or full off.

Open Coil Elements – elements with the Nichrome resistance wire exposed. Designed to heat by radiation and/or convection.

Open Coil Oven Elements – ribbon wound open coil elements designed specifically for use in ovens.

Open Loop Control – a control system with no sensing feedback.

Open Sensor Output Command – for some PID controls, allows selection of shut down or switch to pre-assigned power output (i.e. 30%), in the event of an open sensor.

Output Limit – for some PID controls, allows selection of a maximum percent of full power. Useful of heater is oversized, or for fast heat up followed by close control.

OSHA – US Government agency, Occupational Safety and Health Administration (or Agency). Specifies and enforces safety in the workplace.

Over-the side Immersion Heaters – immersion heaters designed for use in open top tanks. A wide variety of sheath materials and coatings are available to heat most solutions Risers to terminal housings are provided, as well as optional mechanical thermostats for some models.

Overshoot – excursion of temperature above the set point.

P

Percentage Timing Input Controllers – are motor driven adjustable duration cam devices. These provide an adjustable duty cycle, for a time base of 15 or 30 seconds. Useful for intensity (open loop) control. Not for use with tungsten quartz radiant heaters.

Phase – time based relationship between an intermittent function and a reference. Electrically, the expression is in angular degrees to describe the voltage or current relationship of two alternating waveforms.

Phase Angle Control – SCR firing mode in which the SCR's are turned on for a portion of each half cycle. Necessary for high inrush and/or inductive loads, such as tungsten (quartz lamp) heaters and transformers.

Phase Proportioning – a temperature control form where the power supplied to the process is controlled by limiting the phase angle of the line voltage.

PID – three mode temperature control–proportional, integral (automatic reset), derivative (rate).

Polarity – having two oppositely charged poles; one positive, one negative.

Potting – The sealing of components with a compound such as epoxy to protect against moisture and other contaminants.

Process Air Heaters – component heaters or complete assemblies for heating low pressure, high volume air for processes. Single elements of 475 watts to duct heaters of 300kw are included in the selection.

Process Alarm – a fixed alarm or secondary set point value independent of the primary set point. Should a process value exceed this value, an alarm condition would register.

Process Radiant Heaters – heaters providing a variety of wavelengths of radiant energy for heating processes, drying parts, freeze protection, etc. Many types and sizes are available.

Process Value – the indicated value of the parameter being measured/controlled.

Process Variable – the parameter being controlled or measured such as temperature, relative humidity, flow, level, pressure, etc.

Proportioning Band – (or proportional band) the temperature band in degrees within which a control's proportioning function is active. The width is usually adjustable, and is expressed in degrees or as a percent of span.

Technical Information

Thermal System Glossary *(cont'd.)*

Proportioning Control Mode – when process temperature approaches set point and enters the proportioning band, the output is switched on and off at the established cycle time. The change in power to the load provides a throttling action which results in less temperature overshoot. This cycling will continue until on and off times are equal.

Protection Head – a junction box for the protection of the sensor to extension wire connection. Protection heads can provide mechanical, moisture, and explosion area protection.

psia – pounds per square inch absolute. Pressure reference to a vacuum.

psig – pound per square inch gauge. Pressure reference to ambient air pressure.

Q

Quality of Steam – the relative amount of liquid present in saturated steam as a percent of the total weight. The quality of steam is 100% less the percent liquid. Dry saturated steam has a quality of 100%.

Quartz Lamp Radiant Heater – a heater in a reflector, using a tungsten filament quartz tube heater for the radiant source. The best source when the heater must be able to be turned off quickly when the line stops. Intensity control must use phase angle fired SCR's.

R

Ramp – a programmed rise in temperature.

Range – an area between two limits in which a measurement or control action takes place. Typically expressed in upper and lower limits.

Rankine – an absolute temperature scale based upon the Fahrenheit scale with 180˚ between the ice point and boiling point of water. 0˚F = 459.67˚R.

Rate (derivative) – a control function that measures the rate of increase or decrease of the system temperature and brings the control into an accelerated proportioning action. This mode prevents an overshoot condition at initial heat-up and with system disturbances.

Rate Time – the interval over which the system temperature is sampled for the derivative function.

Remote Setpoint – on some controllers, an external 4-20 mA signal, or similar, will change the setpoint of a control. Good for remote computer system control or cascading.

Remote Shutdown – a feature on some SCR units, permitting the shutdown of output from a remote contact opening or closing.

Repeatability – the ability to give the same output or measurement under repeated identical conditions.

Repressed Bends – required when a tubular heater is bent to tighter radius than permitted for customer bending. Repress dies restore the internal compaction of the magnesium oxide to prevent voids, which may result in premature heater failure.

Resistance – the resistance to the flow of electric current measured in ohms.

Resolution Sensitivity – the amount of temperature change that must occur before the control will actuate. It may be expressed in temperature or as a percentage of the control's scale.

Response Time – In analog instruments, the time required for a change of the measured quantity to change the indication. In sensors, the time required to reach 63.2% of the step change.

Retransmit Output – analog output scaled to the process or the set point value.

Ring and Disc Heaters – component heaters which are flat and circular. They are usually used to heat by clamp on conduction. Variety of sizes offered allows for nesting.

RS232 or RS 422-485 Input/Output Signal – A serial interface suitable for connection between a digital control and a personal computer, a host computer or printer.

RTD – a temperature sensing probe of finely wound platinum wire that has a linear resistance change for a corresponding temperature change. The resistance increases as the temperature rises. A base resistance of 100 ohms at 32˚F is the industry (DIN) standard.

S

Saturation Temperature – the boiling temperature of a liquid at the existing pressure.

SCFM – Volumetric flow rate in cubic feet per minute at 60˚F (15˚C) and standard atmospheric pressure.

SCR – Silicon Controlled Rectifier

Secondary Insulating Bushings – porcelain bushings designed to allow certain strip heaters to be electrically isolated from ground, when using on higher voltages for air heating. The heater tabs must be punched at the factory to accommodate the bushings.

Self-Regulating – refers to a type of heat trace cable, which has a decreased wattage output for increasing temperature.

Self-tune – an internal program in some PID controllers, which allows the control to experience the process and internally calculate parameters to obtain good process control operation.

Serial Interface – the hardware and wiring to connect control(s) with digital communications to a computer. Typical choices are RS232 (single drop), RS 422, 458 (multi-drop).

Sensor Breakdown Protection – circuitry which ensures safe process shut down in the event of sensor failure.

Technical Information

Thermal System Glossary *(cont'd.)*

Sensor Selection – a menu or hardware feature on most indicating controls which allows selection of a number of thermocouple types, RTD's and /or other sensors

Serial Communications – A method of transmitting data between devices.

Set Point – control setting to achieve or maintain temperature.

Screw Plug Immersion Heaters – immersion heaters, which mount with a screw plug, typically with a standard NPT thread. Most have an available selection of terminal housings for various environments. Some also include built-in mechanical thermostats.

Shape Factor – in radiant applications, the amount of energy received by the target relative to heater rating and distance to the target.

Sheath – the outer shell of a heating element, usually metal. Typical materials are: copper, steel, stainless steel alloys, and others. Provides mechanical protection and a ground path.

Sheath Length – the length of the sheath measured without the terminals or protruding terminal pins. Typically held within one percent for Chromalox tubular heaters.

Shield – material surrounding a conductor(s) to prevent interference of electrostatic or EMI from external sources.

Shorted SCR Detection – circuitry in some SCR's to detect a shorted SCR in a power control module. Usually the output can be an alarm to alert operator that unit needs service.

Shunt Trip – a coil, designed to turn off the main disconnect on a panel, when energized. Typically used for large SCR panels, to drop the load if high limit is reached.

Single End Tubular Heaters – tubular heaters with both electrical connections located at one end of heater. Simplifies wiring.

Slide Wire Feedback – A potentiometer that varies resistance in response to a valve position. This provides valve position information to the valve controller.

Soak – To raise the temperature of a metal object in a heated environment to produce a metallurgical change. Also, a pre-programmed time to provide a set point to a process, as used in a ramp-soak program.

Soft Metal Melting Pot – an open top vessel designed to melt solder, tin and/or lead.

Soft Start – reduces voltage on initial start-up which reduces power to the heaters.

Solid State Relay – a solid state switching device which completes or breaks a circuit electrically with no moving parts.

Span – the difference between the upper and lower limits of a controller's range.

Specific Gravity – the ratio of mass of any material to the same volume of pure water at 4°C.

Specific Heat – the ratio of thermal energy required to raise the temperature of a mass of material 1 degree to the thermal energy required to raise an equal mass of water 1 degree.

Speed of Response – time needed for a temperature change occurring at the sensor to be translated into a control action.

Spring Loaded – refers to sensor probes designed for use in thermowells. The probe has a spring, which forces the tip of the sensor to make good contact with the inside end of a properly chosen thermowell.

Stability – the ability of an instrument or sensor to maintain a constant output when a constant input is applied.

Standard – reference point from which references or calibrations are made.

Steam Boilers – automatically provide a source of steam for processes or other uses. Boilers are available in a wide variety of sizes and styles. Accessories include automatic blowdown, condensate return systems, steam separators and more

Strip Heaters – heating elements with a rectangular cross section, usually used to heat objects by clamp on conduction or heating air by free or forced convection.

Super Heating – the heating of a liquid above its boiling temperature without changing to a gaseous state; or the heating of a gas considerably above the boiling temperature.

Surge Current – a higher than nominal current of short duration occurring when power is initially applied to loads such as self regulating heat cable and tungsten filament quartz radiant heaters.

T

Temperature Gradient – the range of temperature variations at various physical locations throughout a thermal system.

Tera – the prefix for one trillion(T).

Terminal Pin – a pin in the end of tubular and similarly constructed heaters to which the resistance winding is attached. The pin extends out of the heater and is attached to a terminal to facilitate wiring.

Terminals – the means to attach wiring to heaters. For tubular heaters, a wide variety are available to accommodate wires, lugs, or 1/4 inch push on connectors.

Thermal Conductivity – the property of a material to conduct heat.

Thermal Expansion – an increase in size due to an increase in temperature.

Thermal Lag – the time delay in the distribution of heat throughout a thermal system.

Technical Information

Thermal System Glossary *(cont'd.)*

Thermal System – a series of components arranged and designed to provide heat. The four elements or components compromising a Thermal System are:

1) work or load
2) heat source
3) heat transfer medium
4) control system

Thermistor – a temperature sensing probe manufactured of a mixture of metal oxides then encapsulated in epoxy or glass. A large change in resistance is exhibited proportional to a change in temperature. The resistance usually decreases as temperature rises.

Thermocouple – a temperature sensing probe consisting of the junction of two dissimilar metals which has a millivolt output proportional to the difference in temperature between the “hot” junction and the lead wires (cold junction).

Thermowell – a closed-end tube into which a temperature sensor is inserted to isolate it from the environment.

Thin Blade Heaters – tubular type heaters having a 1 / 4/ by 1 inch cross section. Available in single or three phase models

Touch Safe Design – optional shields available on some SCR power control modules, reduce the possibility of personnel coming in contact with high voltage.

Transducer – a device that converts a measured variable into another form which is the transducer’s output. A thermocouple transforms heat to a millivolt output.

Transmitter – a device used to transmit temperature data from the sensor.

Tubular Element – cylindrical component heating element made with a metal sheath, enclosing a magnesium oxide surrounded Nichrome resistance winding. Cross section may be round, heart shape or flat pressed.

U

Undershoot – excursion of temperature below set point.

Underwriters’ Laboratories (UL) – a third party approval agency for components and finished products.

Ungrounded Junction – A thermocouple junction fully insulated from the sheath.

User Selected Security Code – a feature on some PID controls, allows the selection of an unique code, if the default codes are compromised.

V

VDE – an independent, German third party testing organization for product safety.

Viscosity – the inherent resistance of a substance to flow

Voltage – an electrical potential, which is measured in volts.

W

Wattage – a unit of measurement of electrical power. In a resistive circuit, VI = W (See Ohms Law formulas).

Watt Density – the rated wattage of an element per unit of surface area. Usually expressed in watts per square inch.

Welded – one common method of attaching sensor probe to threaded hub. Welding produces a moisture proof, mechanically strong bond.

Z

Zero Voltage (or Zero Crossover) Switching – completing or breaking of a circuit when the voltage wave form crosses zero voltage.

Notes